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Alternative Methods for Disposal of Low-Level Radioactive Wastes

ORIGINAL

Task 2e: Technical Requirements for Shaft Disposal of Low-Level Radioactive Waste

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Prepared for
U.S. Nuclear Regulatory
Commission

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ABSTRACT

Current practice in the US for disposal of commercial low-level radioactive wastes (LLW) is burial in shallow trenches. In 1983, approximately 110,000 cubic meters of these wastes were disposed of at the three operating commercial sites. Three additional sites have ceased operations in the past decade and are awaiting technical and institutional determinations that will allow for final closure. Although shallow land burial in trenches may continue to be practiced, it is likely that techniques for engineered disposal will be introduced to the NRC or states for licensing consideration within the next few years.

The shaft disposal alternative is one of several methods that may be proposed. In this report, the term shaft disposal refers to a near-surface disposal alternative in which the wastes would be disposed of in shafts or boreholes augered, bored, or sunk by any other conventional method.

The experience and knowledge gained with this method are described and updated in this report, including US Department of Energy (DOE) demonstration projects at the Nevada Test Site and the Savannah River Plant, storage at Bruce Nuclear Power Development site and Chalk River Nuclear Laboratory in Canada, and research and development projects in Sweden and West Germany.

Extrapolation of this short-term experience indicates that the shaft disposal method is capable of satisfying the performance objectives specified by the NRC in 10 CFR Part 61 Subpart C.

A generic description of the features and components and operation of a shaft disposal facility is provided. Features and components that could enhance the long-term performance are also described, including site conditions for which they would be applicable.

The existing criteria developed for near-surface disposal (10 CFR Part 61 Subpart D) were assessed for applicability to the shaft disposal method in Task 1 of this study and were reassessed in Task 2, as reported herein. Without exception, these criteria were found to be applicable in the reassessment. These conclusions differ slightly from the Task 1 findings in which modifications of 3 existing criteria were recommended.

Additional technical considerations that should be addressed are recommended. These considerations include:

a. The need for assessment of the occurrence and potential adverse impacts from dispersive soils, corrosive soils, solution cavities, liquefiable soils, expansive soils and areas undergoing land subsidence.

b. The need to plan for individual disposal unit closure.

c. The need to consider requirement of features that could enhance the long-term performance of the facility.

d. The need to consider the differences in philosophy required for siting, designing, closing, and monitoring any disposal facility that would place waste packages below the water table, as opposed to current practices of disposal above the water table.

e. The need for and possible advantages and disadvantages of replacing monitoring points when they become inoperative, as opposed to decommissioning and closing them as satisfactory performance is established.

f. The need for consideration of the desirability of a short-term highly reliable monitoring program that could be scaled back as the facility's satisfactory performance is established.

g. The need for submittal of a detailed plan for remedial actions should they become necessary. This plan should identify specific scenarios that would trigger specific actions and the reaction times involved.

Finally, research is recommended for unresolved issues that were not addressed by this study. These issues include questions about the long-term durability and performance of materials used in engineered barriers. Available information should be organized on sealing materials and methods, backfill, covers, caps, and linings. This information should then be supplemented by research targeted at identified deficiencies.

Continued support of research into improved waste packages and sorbent barriers is also recommended.

The potential economic advantage of segregation prior to disposal, should be investigated, along with development of sound economic analyses of the various disposal options, so that states may make rational decisions among their waste management and disposal options.

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This report presents the results of subtask 2e of the US Nuclear Regulatory Commission (NRC) - sponsored study, "Criteria for Evaluating Engineered Facilities", performed by personnel of the US Army Engineer Waterways Experiment Station (WES) Geotechnical Laboratory under interagency agreement no. NRC-02-83-046 dated 31 May 1983.

Mr. James Shaffner was the NRC technical monitor. His advice and support are greatly appreciated. Mr. David Bennett was principal investigator and author of this report.

The work was performed under the general supervision of Mr. J. S. Huie, Chief, Rock Mechanics Application Group (RMAG), Engineering Geology and Rock Mechanics Division (EGRMD), Geotechnical Laboratory (GL) and Dr. Don C. Banks, Chief, EGRMD.

Dr. William F. Marcuson III was Chief of the Geotechnical Laboratory during this study.

Mr. Fred Brown was Technical Director of WES. COL Robert C. Lee was Commander and Director of WES during this study.

1. INTRODUCTION

1.1 Background

The Atomic Energy Act of 1954 and the Energy Reorganization Act of 1974 gave the US Nuclear Regulatory Commission (NRC) the responsibility for assuring and maintaining public health and safety, as may be affected by commercial nuclear facilities, including facilities for the disposal of low level radioactive waste (LLW).

The National Low Level Radioactive Waste Policy Act of 1980 (Public Law 96-573) gave the individual states responsibility for the management and safe disposal of all commercial LLW generated within their borders. The act provides, subject to congressional approval, that each state may enter into regional compacts with neighboring states to establish and operate regional disposal sites.

The NRC has established uniform procedures for licensing and regulating the disposal of LLW. The procedures are set forth in the Code of Federal Regulations 10 CFR Part 61. Subpart D and related regulatory guidance provide specific technical criteria for land disposal. Specific sections of Subpart D provide technical criteria related to siting, design, operations and closure of a near-surface disposal facility. Subsections were reserved for methods other than near-surface disposal.

Current practice is to dispose of commercial LLW by burial in shallow trenches. In 1983 approximately 110,000 cubic meters of these wastes were disposed of at the three commercially operated disposal facilities. Waste disposal at three additional sites has ceased in the past decade and these sites are awaiting permanent closure.

Although shallow land burial in trenches may continue to be practiced, it is likely that other techniques for engineered disposal may be submitted to the NRC or the states for licensing consideration within the next few years. It is important that the NRC establish uniform criteria, or guidance, by which engineered facilities may be evaluated and that such criteria or guidance be compatible with the performance objectives set forth in 10 CFR Part 61 Subpart C.

1.2 Purpose and Scope

The overall purpose of this study was to ensure that the criteria contained in 10 CFR Part 61, paragraphs 61.50 through 61.53 or guidance as required to completely evaluate 5 alternative methods of LLW disposal were available to NRC and the states. The methods considered in this study were aboveground vaults, belowground vaults, earth mounded concrete bunkers, mined cavities, and shafts. Criteria or guidance related to site suitability, design, operations, closure, and monitoring were to be assessed. Where judged to be appropriate, recommendations were to be made to modify existing criteria and to address additional technical issues.

Guidance related to the implementation of criteria for acceptable waste forms and classes that would be appropriate for disposal in specific engineered facilities are also important areas of consideration. However, development of guidance for acceptable waste forms or waste classifications was beyond the scope of this study.

Development of conceptual designs were also not within the scope of this study. However, important features of the various alternatives were illustrated and discussed as they pertain to the satisfaction of the performance objectives. Although segregation of wastes prior to disposal in engineered facilities may be desirable for economic or political reasons, segregation has not been assumed as a requirement for this study.

Cost estimates were not prepared or reported for any of these alternative methods. It is recognized that guidance on conceptual designs and acceptable waste forms and classes appropriate for disposal using these alternatives would be useful to the states or individuals considering them, and that detailed costs would be an important consideration in their adoption. However, the most important issues are whether these methods can meet the performance objectives of Subpart C and how their performance can be judged.

The study was divided into 3 main tasks. Previous work was described in the task 1 report (Bennett and others, 1984), and included descriptions of all 5 alternatives, summaries of the experience with each method, and an initial assessment of the applicability of existing technical criteria relating to site suitability, design, operations, closure, and monitoring.

This report, one of a series, contains the results of subtask 2e of the investigation. Separate reports were prepared for each method investigated. The reports pertaining to the aboveground vault, belowground vault, earth mounded concete bunkers, and shaft disposal methods were each issued as one of a series of 4. Although each of these methods has some contrasts with existing shallow land burial practice, they are accurately considered near surface disposal methods.

However, the mined cavity disposal alternative is quite different from existing near surface disposal practice. Consequently, during the course of the study, the NRC decided to deal with this method separately from the others.

1.3 Organization

Each of the task 2 reports has been organized in parallel format as described below.

Each report shares a common introductory section. In Part 2, the performance objectives are listed, the experience with the disposal alternative is summarized and updated, the unit operations and features and components of the particular alternative disposal facility are described, and the performance capabilities are summarized.

The technical criteria recommendations are developed in Part 3. The criteria are reassessed one by one, drawing from the assessment and conclusions made in the Task 1 report. The organizational scheme used is to list each criterion as it appears in 10 CFR 61, and discuss its objective and relevance to shaft disposal. Next a recommendation is made to:

a. Retain the criterion as is.

b. Not apply the criterion in the evaluation of the particular alternative as it is inapplicable.

c. Modify the criterion to make it applicable to the particular alternative.

Any recommended modifications to existing criteria are underlined. Any departures or changes from the position taken in the Task 1 report are noted and explained. This procedure is followed for each criterion.

At the end of each criteria section, i.e. site suitability, design, etc., suggested additional technical considerations that should be addressed are discussed. These considerations (some of which are implied from 10 CFR 61.12) may form the basis for additional criteria, if judged to be necessary and correct by the NRC. Specific supplemental criteria are not given in prescriptive language. Rather, the issues that should be addressed and the reasoning behind them are stated. This method of presentation is thought to be more appropriate than offering specific criteria, as it allows the NRC to consider those issues and develop specific wording that it considers appropriate on a point by point basis. Alternatively, the NRC may wish to provide guidance without changes or additions to existing criteria.

In Part 4, conclusions and recommendations are offered on the feasibility of the disposal concept, the modified criteria and supplemental considerations, and on unresolved issues and research required to resolve them.

All references are listed after the body of the report. A glossary of major terms follows the references.

Because concrete is likely to play an important role in engineered disposal facilities, factors that impair long term durability of concrete and design and construction practices that can be used to minimize adverse impacts are discussed in Appendix A.

2. THE SHAFT DISPOSAL ALTERNATIVE

In the following paragraphs, the alternative is described, including major components or features of the method, the experience gained with its use is summarized and updated from the Task 1 report, and performance capabilities are discussed. Features or components that could enhance the method's performance are also discussed.

The discussion at the end of this section of performance capabilities of the shaft disposal alternative is directed toward satisfaction of the performance objectives.

It should be noted that for any method to be considered by the NRC for licensing for disposal of low-level radioactive wastes, it must be capable of satisfying the performance objectives of 10 CFR Part 61 Subpart C (paragraphs 61.40 through 61.44). These performance objectives are quoted below.

2.1 Performance Objectives

Paragraph 61.40 - "General requirement. Land disposal facilities must be sited, designed, operated, closed, and controlled after closure so that reasonable assurance exists that exposures to humans are within the limits established in the performance objectives in paragraphs 61.41 through 61.44."

Paragraph 61.41 - "Protection of the general population from releases of radioactivity. Concentrations of radioactive material which may be released to the general environment in ground water, surface water, air, soil, plants, or animals must not result in an annual dose exceeding an equivalent of 25 millirems to the whole body, 75 millirems to the thyroid, and 25 millirems to any other organ of any member of the public. Reasonable effort should be made to maintain releases of radioactivity in effluents to the general environment as low as is reasonably achievable."

Paragraph 61.42 - "Protection of individuals from inadvertent intrusion. Design, operation, and closure of the land disposal facility must ensure protection of any individual inadvertently intruding into the disposal site and occupying the site or contacting the waste at any time after active institutional controls over the disposal site are removed."

Paragraph 61.43 - "Protection of individuals during operations. Operations at the land disposal facility must be conducted in compliance with the standards for radiation protection set out in Part 20 of this chapter (10 CFR Part 20), except for releases of radioactivity in effluents from the land disposal facility, which shall be governed by Paragraph 61.41 of this part. Every reasonable effort shall be made to maintain radiation exposures as low as is reasonably achievable."

Paragraph 61.44 - "Stability of the disposal site after closure. The disposal facility must be sited, designed, used, operated, and closed to achieve long-term stability of the disposal site and to eliminate to the extent practicable the need for ongoing active maintenance of the disposal site following closure so that only surveillance, monitoring, or minor custodial care are required."

2.2 Experience with the Method

The use of shafts for storage or disposal of low- or intermediate-level radioactive waste as an alternative to shallow land burial of these wastes has been the subject of investigations reported by DOE (Dickman and Boland, 1983; Card and others, 1981; Cohen and others, 1982, Hooker, 1982, Cook, 1984; Towler, Cook, and Peterson, 1983), the Atomic Energy of Canada, Ltd (AECL) (Morrison, 1974; Feraday, 1982 and 1983; Beamer and others, 1982; Charlesworth and Carter, 1982; Dixon, 1981; Harmon and others, 1984) and by the NRC and other agencies (MacBeth and others, 1978 and 1979). These investigations and demonstration projects are discussed below.

2.2.1 DOE Greater Confinement Disposal Test at Nevada Test Site

At the Nevada Test Site (NTS), the DOE is currently evaluating the use of large-diameter augered holes for disposal of high specific activity low-level radioactive wastes. The objectives of this test are to define the tritium diffusion rate through site soils and to achieve greater confinement and isolation of greater than Class C low-level wastes and reduce risks of exposure at the ground surface (Dickman and Boland, 1983).

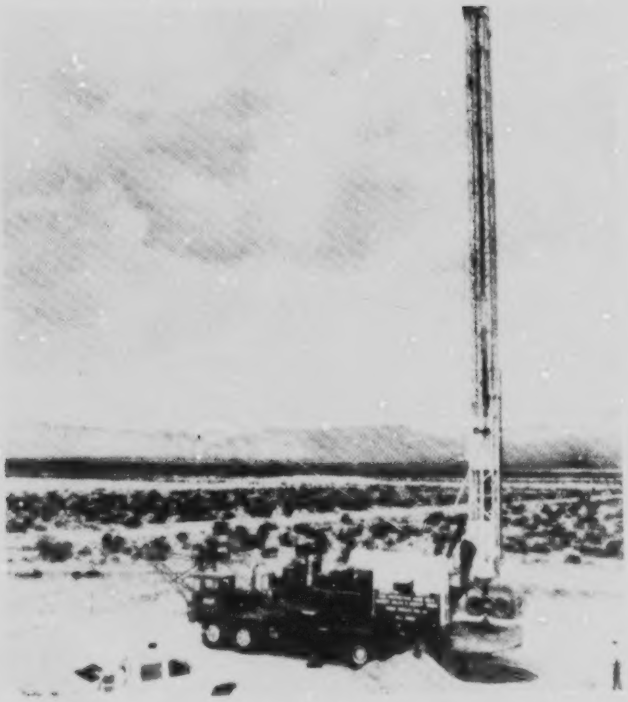
The DOE Greater Confinement Disposal Test (GCDT) began in 1981 and waste emplacement began in December 1983. The basic design of the experiment included a central waste shaft, surrounded by nine smaller holes for instrumentation. The waste disposal shaft was 10 ft diameter and 120 ft deep.

The main hole was sunk with a large auger rig such as shown in Figure 1. Figure 2 is a schematic of the waste shaft and instrument holes. The central shaft was also instrumented.

Only 30 ft of the waste shaft was used for waste disposal. The bottom 20 ft was backfilled over the emplaced instruments. After the wastes were emplaced, the waste shaft was backfilled to slightly above the ground surface and the monitoring phase began. No compaction was applied to the backfill out of concern for protection of the instrumentation cables.

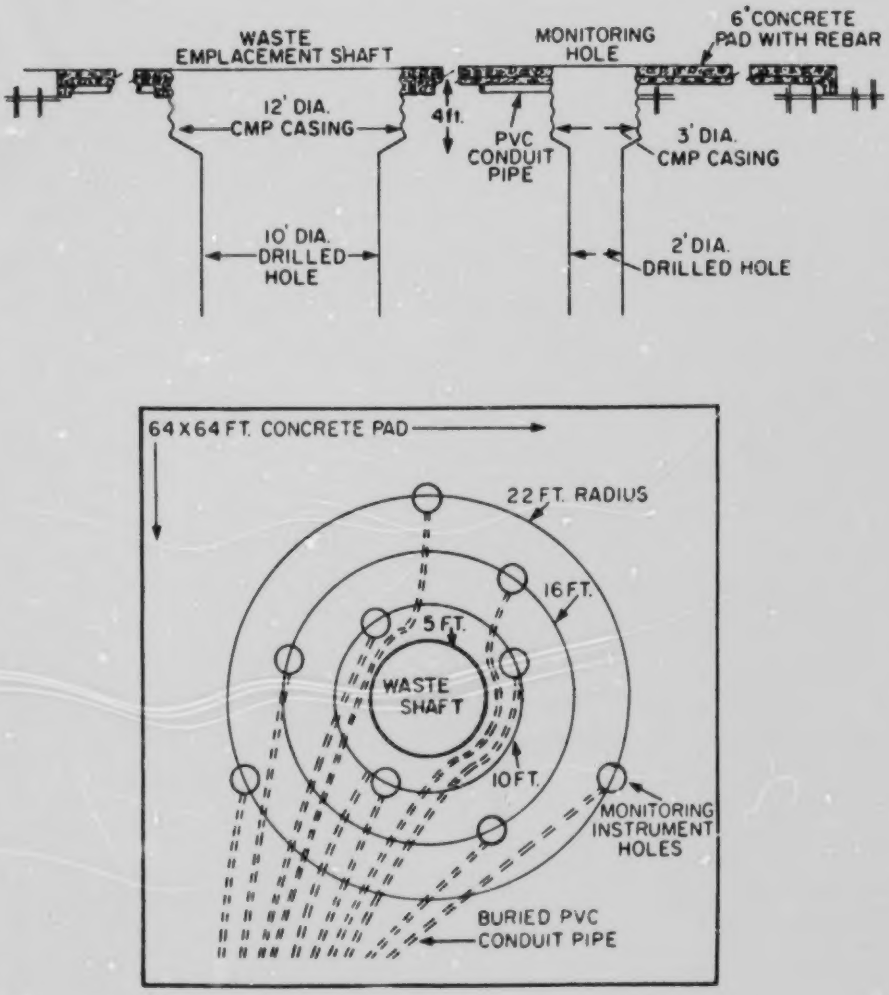
It should be noted that this test was conducted under closely supervised conditions in an area almost ideally suited to construction of large augered holes and that much experience has been gained at NTS with this construction method from the extensive weapons testing programs conducted there.

A similar study is also being conducted at NTS under DOE funding (Dickman and Boland, 1983). In this experiment, a 10-ft-diam hole was augered 30 ft deep from the bottom of a previously excavated trench 18 ft deep. A 6-ft-diam casing was then lowered into the hole. Holes were cut into the casing



A truck-mounted drilling rig used by the DOE for the Greater Confinement Disposal Test at the Nevada Test Site. The auger rig drilled a 10-ft-diam, 120-ft-deep waste disposal shaft and the surrounding instrument shafts.

Figure 1. Auger drill rig, Greater Confinement Disposal Test. Source: Reynolds Electrical and Engineering Co., "Greater Confinement Disposal Test at the Nevada Test Site, June 1983," DOE/NV/00410-79


WASTE EMPLACEMENT SHAFT
MONITORING HOLE
6" CONCRETE PAD WITH REBAR
12' DIA. CMP CASING
4 ft.
PVC CONDUIT PIPE
3' DIA. CMP CASING
10' DIA. DRILLED HOLE
2' DIA. DRILLED HOLE
64 X 64 FT. CONCRETE PAD
22 FT. RADIUS
16 FT.
5 FT.
WASTE SHAFT
10 FT.
MONITORING INSTRUMENT HOLES
BURIED PVC CONDUIT PIPE

Shown are plan and elevation views of the waste shaft and instrumentation holes used for the Greater Confinement Disposal Test at the Nevada Test Site. The basic design consists of a centrally located waste emplacement shaft surrounded by nine instrumentation holes for assessing the potential for radionuclide migration.

Figure 2. Waste shaft and instrumentation holes, Greater Confinement Disposal Test. (Source: Reynolds Electrical and Engineering Co., "Greater Confinement Disposal Test at the Nevada Test Site, June 1983," DOE/NV/00410-79)

at 5-ft vertical spacing, and horizontal borings were drilled into the soil at these locations to install soil atmospheric moisture samplers.

A 250,000 curie tritium source was emplaced in the hole. Besides the subsurface instrumentation and air samples, plant uptake and tritium migration through the cover were to be measured.

2.2.2 Storage of TRU Wastes at DOE Oak Ridge National Laboratory

At Oak Ridge National Laboratory (ORNL) in Tennessee, transuranic (TRU) wastes are being stored in shallow holes at Solid Waste Storage Area No. 6. The geology of this area may be characterized as a steeply dipping, faulted, weathered shale forming the ridges bounded by incised tributaries of White Oak Creek.

Only the upper portions of the ridges are used for storage to take advantage of greater depths to the ground-water table. The average hole depth is less than 21 ft, with an estimated minimum of 2 ft of undisturbed shale maintained between the bottom of the hole and the water table. The holes are about 3 ft inside diameter, spaced on 6-ft centers, and are excavated on an as-needed schedule.

Radioactive waste is transported to the site in reusable shielded containers on flatbed trailers. The containers are lifted by hoist from the trailer and lowered onto a template over the open hole. Figure 3 is a photograph of this operation. A trap door is then opened and the waste is lowered down the hole with a cable and hoist system, or for the lower activity waste, it is simply allowed to fall to the bottom of the hole. The waste is then covered with 1 to 2 ft of soil or until the measured radiation level is verified to be below safe standards. No compaction is applied to the backfill.

The hole may be left open for short periods during fair weather but is covered by a conical sheet metal weather cap during rainy periods. When wastes and backfill reach to within about 4 ft of the ground surface the hole is topped out with loosely placed backfill to within 1-1/2 ft of the surface, 6 in. of concrete is poured into the hole, allowed to set, and the hole is then backfilled to the surface with soil.

Upon completion of a grid of these holes, a surface treatment is applied. About 4 lb per square foot of dry bentonite clay is broadcast and disked into the soil and the area is seeded with grass. When subsidence over the holes has been observed, more soil has been added and these areas were then reseeded.

Piezometers and sampling wells are located around the disposal area. Water samples are taken and water table depths are measured from these holes. No radionuclide migration from augered holes at Storage Area 6 has been detected over the last decade of use.

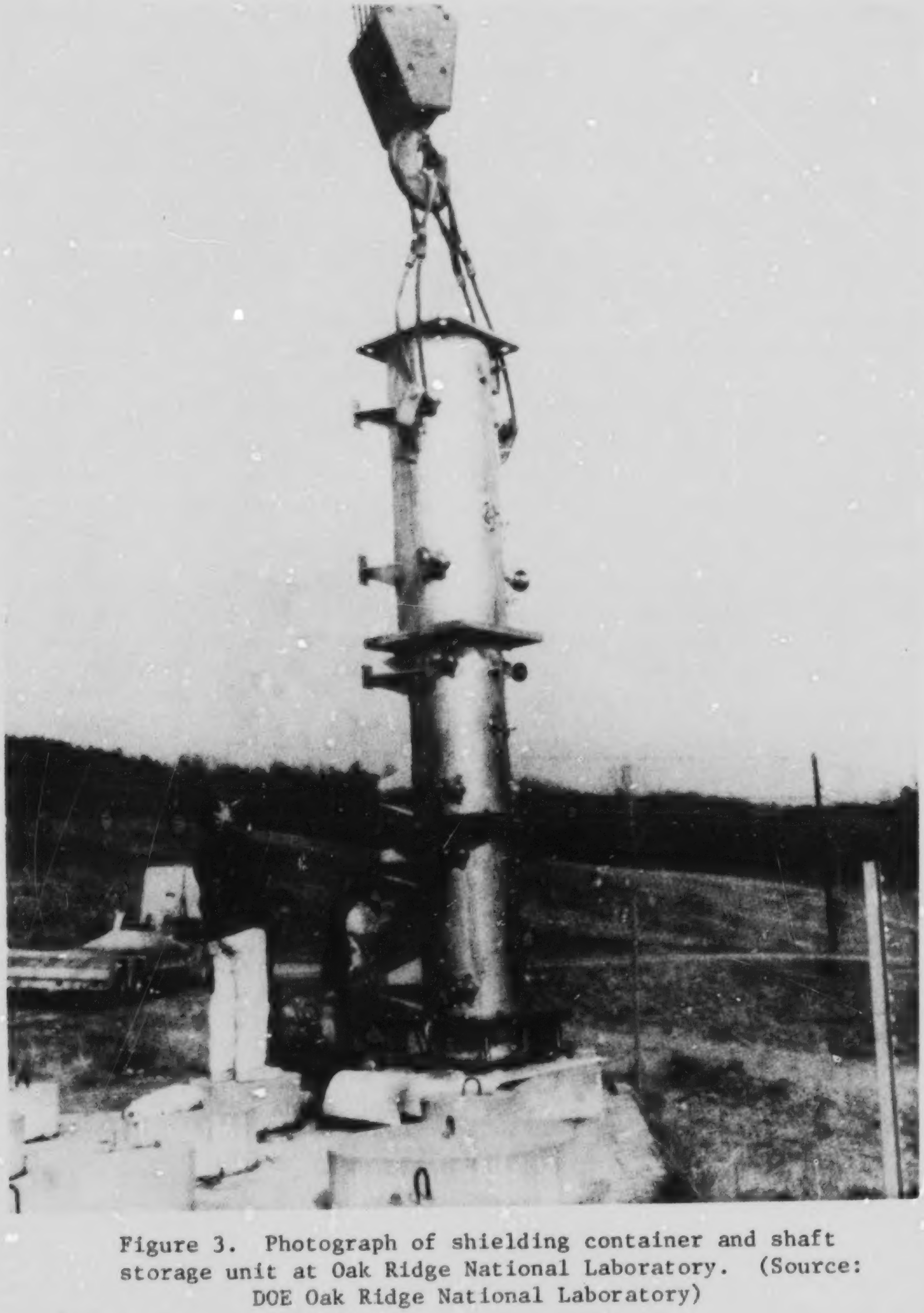


Figure 3. Photograph of shielding container and shaft storage unit at Oak Ridge National Laboratory. (Source: DOE Oak Ridge National Laboratory)

2.2.3 DOE Greater Confinement Disposal Test (GCDT) at Savannah River Plant

At the Savannah River Plant (SRP) near Aiken, South Carolina, DOE and the site operator, E.I. du Pont de Nemours and Co., are carrying out a demonstration project called the GCDT (Cook, 1984; Towler, Cook, and Peterson, 1983; Hooker, 1982). This demonstration project has several objectives and features in common with the GCDT being carried out at NTS. The primary difference is the arid site characteristic at Nevada versus humid South Carolina. Also, this project is probably more practical for actual disposal operations. The NTS project is more accurately termed a field research project.

At SRP, the operator plans to dispose of Class B low-level wastes in shafts 32 ft deep and 9 ft diameter. The water table is relatively shallow at this site which limits the shaft depths. As shown in Figure 4, an array of shafts is planned that will accommodate about 6 years' production of these higher activity wastes. According to Cook, the decision to use this disposal technique resulted from an analysis of the waste stream at the plant. The analysis showed that about 97 percent of the LLW activity was contained within about 5 percent of the waste packages by volume. It is this waste that will be disposed in greater confinement. The much larger volume of lower activity "suspect" wastes will continue to be disposed of by shallow land burial.

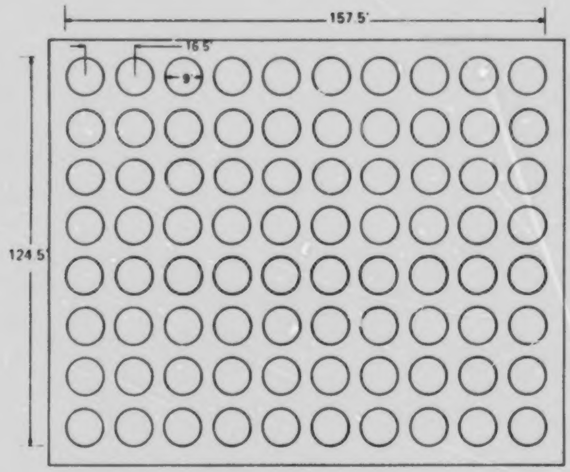
After the shafts are augered, porous cup moisture samplers are placed on the bottom of the shaft. The bottom 2 ft of the hole is then filled with gravel and a grout pad is poured over the gravel. The liner, which is sealed at the bottom, is then lowered into the hole. The lining is fiberglass and extends 20 ft from the bottom of the shaft up to within 10 ft of the ground surface. The grout is allowed to set up around the liner so the liner will not be floated out of the hole by uplift from the liquid grout placed in the annulus between the hole and the liner later.

A 10-ft long steel collar is then lowered into the hole and overlaps outside the fiberglass liner by 1 ft. The top of this collar has a horizontal outer plate with eight grout placement holes 8 in. in diameter spaced around the perimeter. A monitoring well is placed in one of these holes. The holes are grouted and the collar is then withdrawn for reuse later. The fiberglass liner is filled with water during grout placement to resist collapse from hydrostatic loads.

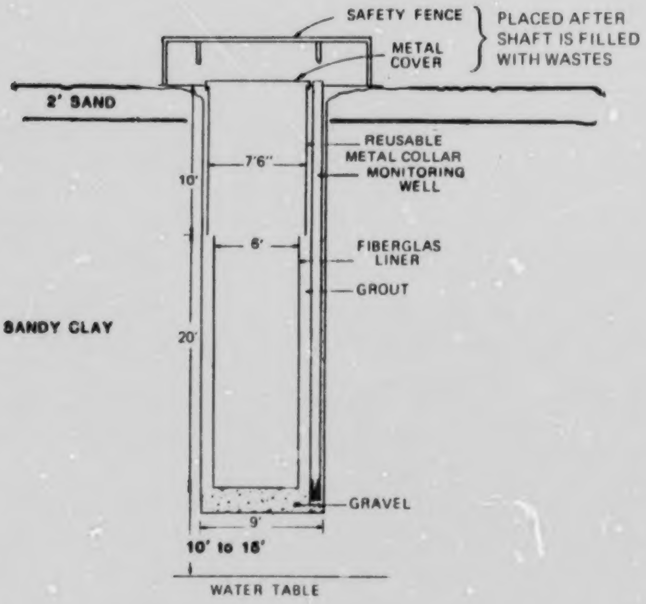
To date 20 shafts have been constructed. Additional shafts will be constructed in sets of 20 or so on an as needed basis (about once a year).

The soil at the site consists of a thin layer of sand (≈2 ft) underlain by a red sandy clay that is quite thick. Reportedly, no gravel, boulders, or rock was encountered while sinking the shafts. This material is typical of site soils and depth to bedrock is hundreds of feet. The water table is at about 45 ft below surface. Since the holes are 32 ft deep, the bottoms of the holes are about 13 ft above the water table.

Most of the wastes will be packaged in 55-gal drums and will be lowered into the hole using a vacuum-lift device. This device is operated by an electric


157.5'
16.5'
9'
124.5'

PLAN


SAFETY FENCE
METAL COVER
PLACED AFTER SHAFT IS FILLED WITH WASTES
2' SAND
REUSABLE METAL COLLAR
MONITORING WELL
7'6"
10'
6'
FIBERGLAS LINER
GROUT
SANDY CLAY
20'
GRAVEL
9'
10' to 15'
WATER TABLE

ELEVATION

Figure 4. Plan and elevation views of Greater Confinement Disposal Test at DOE Savannah River Plant, Aiken, S. C. (Source: E. I. du Pont de Nemours, 1984)

vacuum pump mounted on its frame. Up to eight drums at a time can be lifted. However, for this project, seven drums will be stacked to a layer in the shafts with one in the center surrounded by six. This stacking arrangement is space efficient but will necessitate rehandling the waste after unloading before emplacement in the shafts. The vacuum lift uses one suction head for each drum. The entire assembly is raised and lowered by a crane. Seven layers of drums will be placed in each shaft for a total of 49 drums per shaft. Figure 5 is a sketch of the vacuum lift device and the waste emplacement operation. Figure 6 is a photograph of a vacuum lift unit.

After each layer of drums is placed a layer of grout is placed to shield the wastes and a temporary lid is installed to prevent rain from entering the hole. When all the holes have been filled to within 10 ft of the surface, they will be backfilled with soil to within 4 ft of the surface and then will be capped with concrete. Then 8 ft of soil fill will be placed over the site to shield the wastes and lessen infiltration and runoff potential. If the water table was deeper, the holes could be deeper and the fill would not be needed. The longest horizontal dimension of the vacuum lift frame is 6 ft so the device may have to be modified to fit down the shafts. Prior to obtaining this device, SRP had planned to stack the drums in disposable steel pallets and lower the pallets down hole. However, the vacuum lift should prove to be more economical.

2.2.4 Disposal of LLW and TRU Wastes at Los Alamos National Laboratory

Augered holes have also been used at Los Alamos National Laboratory (LANL) in New Mexico for disposal of solid wastes that required shielding (National Research Council, 1976). Tritium wastes and TRU wastes were first encased in asphalt before placement in these drilled shafts. Contaminated oils were placed in 55-gal drums and stacked in the shafts.

The holes were approximately 2.5 ft diameter and up to 65 ft deep. Some were concrete lined. A rounded surface concrete sealing plug 3 ft thick was poured when each hole was filled. The regional water table depth ranges from 850 to 1050 ft. There is some perched water in the stream connected alluvial aquifers in the canyons but wastes were disposed of only along the tops of the mesas or plateaus.

The precipitation is sparse at this site and infiltration is limited to the upper 10 ft of soil. Purtymun (1973) reported that some tritium was migrating from these shafts in the vapor phase through open joints in the tuff. This report led to the practice of spraying shaft walls with asphalt (National Research Council, 1976).

2.2.5 Storage of LLW at Bruce Nuclear Power Development Site and Chalk River Nuclear Laboratory, Canada

In Canada, "tileholes" or concrete pipes set vertically on concrete foundations with the tops set flush with the ground surface have been used for storage of ion exchange resins and filter canisters at Ontario Hydro's Bruce site and at Chalk River Nuclear Laboratory, Ontario, Canada (Morrison, 1974; Feraday, 1982 and 1983). The tileholes are well above the water table and

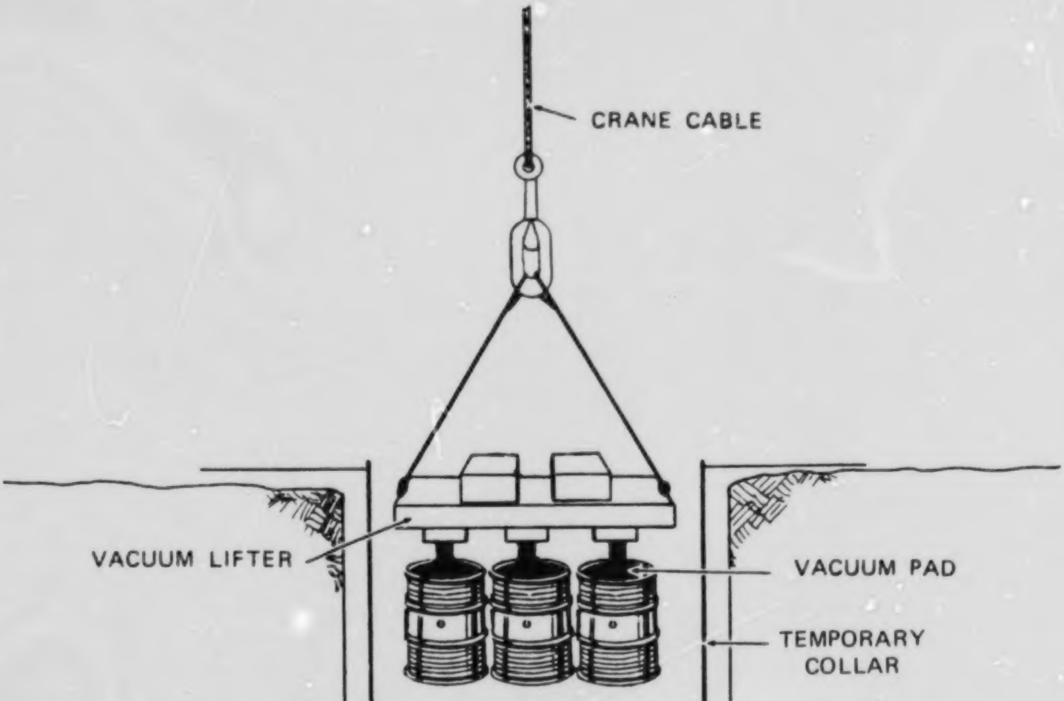

CRANE CABLE
VACUUM LIFTER
VACUUM PAD
TEMPORARY COLLAR
FIBERGLAS LINER
NOT TO SCALE
GROUT
55-GALLON DRUMS (7 PER LAYER)

Figure 5. Elevation view of GCDT shaft, waste drums, and vacuum lift device at DOE Savannah River Plant. (Source: E. I. du Pont de Nemours)

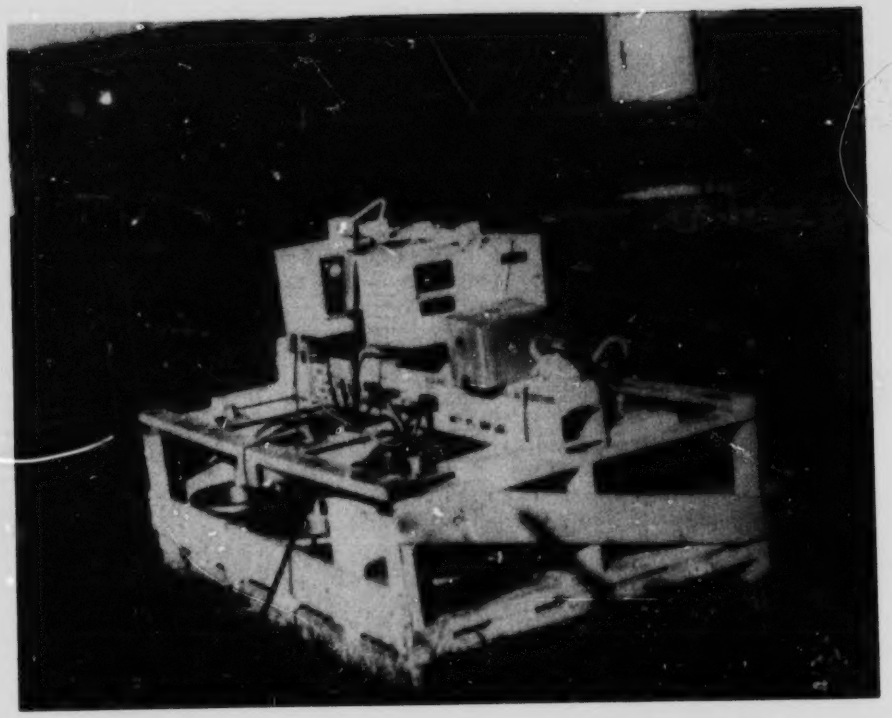


Figure 6. Photograph of vacuum lift device used at Savannah River Plant Greater Confinement Disposal Test. (Source: E. I. du Pont de Nemours, 1984)

an underdrainage system was installed which leads to a monitored and controlled discharge. Figure 7 is a schematic of the tilehole system. Figure 8 is a photograph of a tilehole array under construction. Figure 9 is a photograph of the lightweight covers used for temporary closure. This figure also shows the concrete plugs and asphalt sealant used to close waste-filled shafts.

2.3 Operations and Features of a Shaft Disposal Facility

A disposal facility for LLW that uses shafts as the disposal units would consist of several components or features common to shallow land burial. Some features would be unique requirements for this method. Similarly, some features or components may be considered absolute requirements, while others may be desirable but not essential under all conditions. These features, if incorporated into the design, could improve the waste isolation capabilities of the disposal units and reduce the need for long-term active maintenance.

2.3.1 Unit Operations

The primary unit operations required at a shaft disposal facility and the major features of such a facility are discussed in this context in the following paragraphs.

In general the operation of a shaft disposal facility would be similar in many respects to a trench disposal facility.

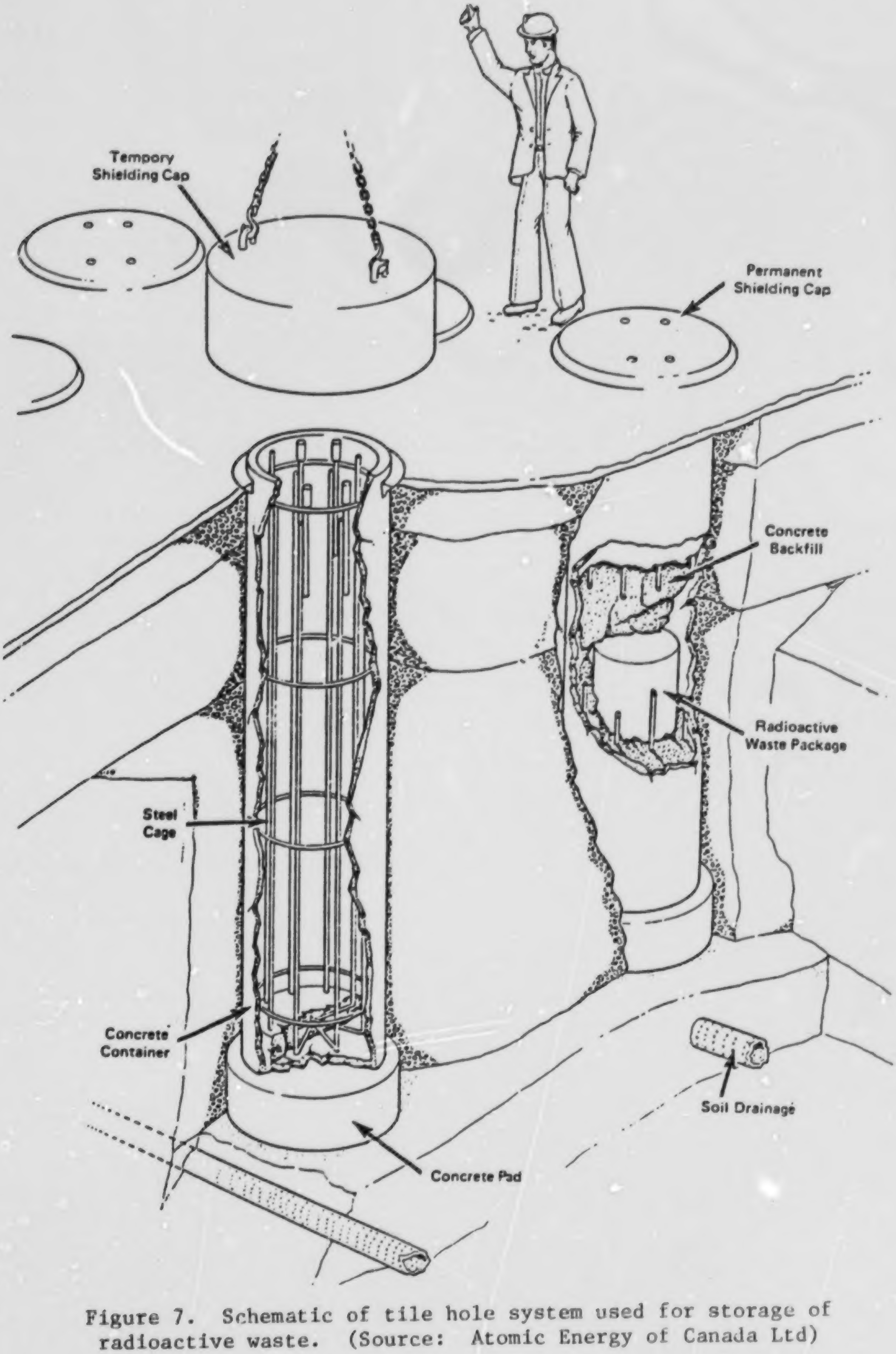
Trucks loaded with wastes would be checked in at the entrance, the cargo and manifest checked, and appropriate instructions given to the driver.

The truck would proceed to the secure operations area, i.e., the actual disposal area, or to a temporary storage area, from which the waste packages would be transferred to disposal later.

The waste packages would be unloaded and placed in the disposal shafts using a mobile crane and special lifting devices. After being unloaded, the truck is surveyed for contamination and washed and decontaminated if necessary before leaving the site.

Other activities would include surveying to establish new disposal area boundaries and disposal unit locations, record keeping for waste receipts, disposal locations, unusual incidents, personnel records including worker exposures, quality control test results, sampling and monitoring data, and permits and licenses.

Sampling and monitoring points must be established and maintained, including surface and subsurface points. Laboratory tests and analyses would be required periodically to verify satisfactory performance and establish a data base from which trends or anomalies could be discerned. Maintenance and repair of equipment and facilities would be required. Personnel training and a certain amount of public relations work would be required.



Tempory Shielding Cap
Permanent Shielding Cap
Concrete Backfill
Radioactive Waste Package
Steel Cage
Concrete Container
Soil Drainage
Concrete Pad

Figure 7. Schematic of tile hole system used for storage of radioactive waste. (Source: Atomic Energy of Canada Ltd)

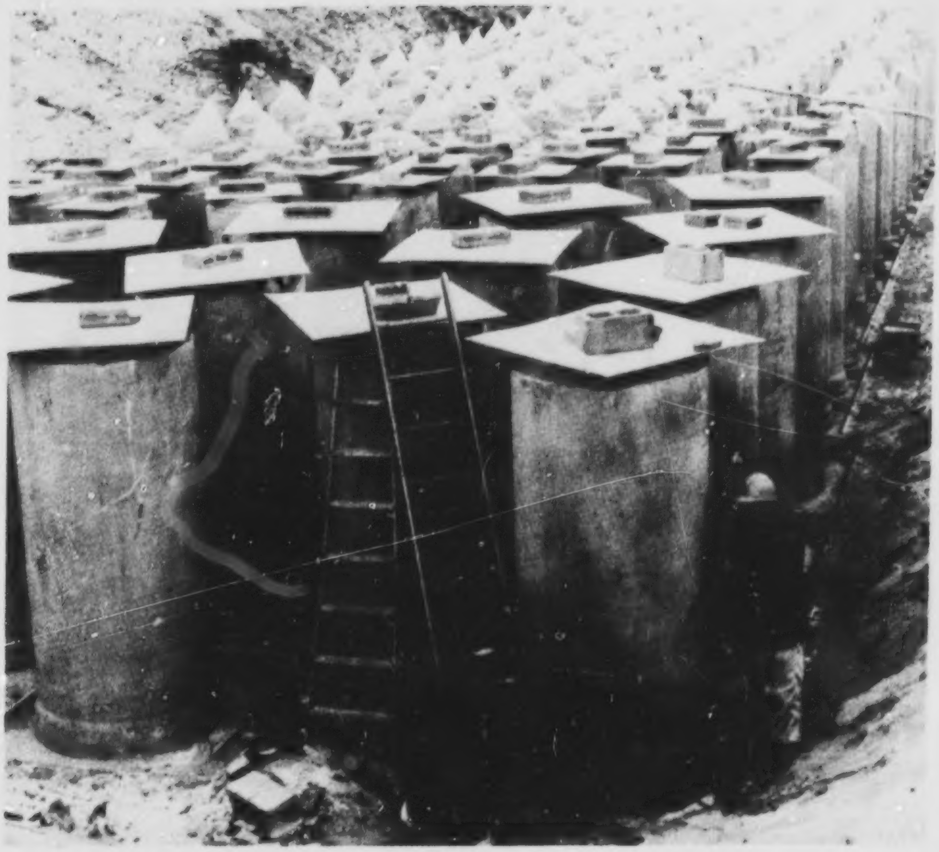


Figure 8. Photograph of tile hole array under construction. (Source: Ontario Hydro)

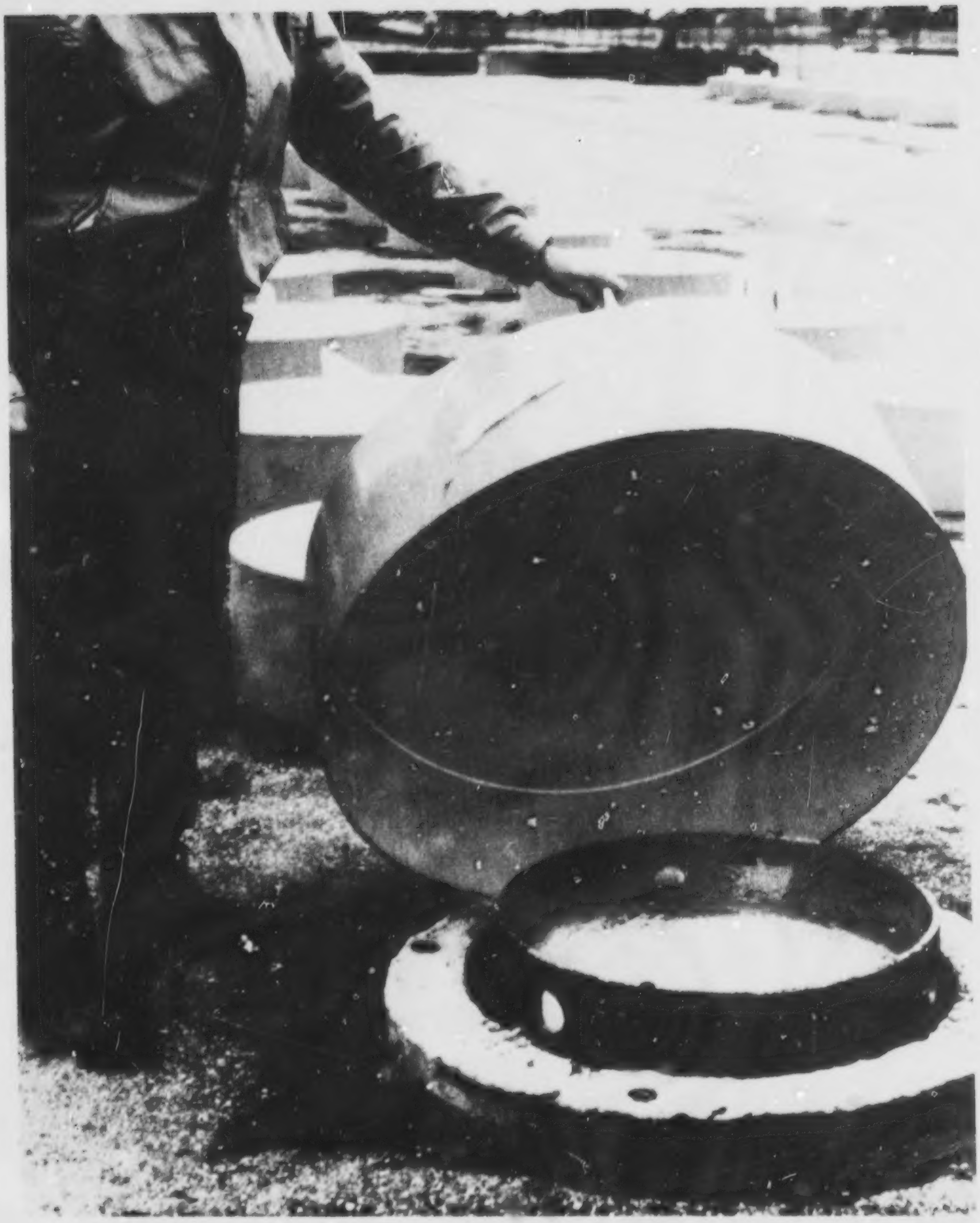


Figure 9. Lightweight covers used for temporary closure of tile holes. Note the concrete plug and bituminous sealant used to close waste-filled shafts. (Source: Ontario Hydro)

Clearing and grading of new disposal areas and establishment and maintenance of runoff control features (surface water management) would be required from time to time.

Additional disposal shafts must be constructed, including necessary appurtenances, such as the lining, drainage blanket, etc.

Placement and compaction of shaft backfill around and above waste packages would be required.

Covers and vegetation must be established and maintained.

Most of these activities would be similar for a shaft or trench disposal facility. Differences would exist in some of the methods and equipment used. For example, instead of using elevating scrapers for trench construction, a drill rig would be used for shaft excavation. Because of the limited side clearance between the waste packages and shaft walls and the inaccessability of the shaft bottom to workers, special lifting and lowering equipment would be required. Remote coupling of the lift to the waste packages would be necessary. Shaft backfilling would probably be accomplished using a clamshell bucket or backhoe, rather than a crawler tractor and blade. Compaction would require the use of small portable equipment, as opposed to a sheepsfoot roller commonly used for compaction of trench covers.

2.3.2 Features and Components

The primary features and components of a shaft disposal facility are listed below:

a. The actual disposal site including the land for disposal areas, buffer zones, and auxiliary operations.

b. Security fences, guard shacks, and truck check in station for control of access and egress.

c. Operations building from which all disposal operations would be initiated.

d. Administration building which should include facilities for office work, records storage and retrieval, including personnel records, visitor waiting room facilities, convenience facilities, and storage areas. Ample parking areas should be provided. The administration building should be outside the secure operations area to minimize the number of employees and visitors that must be checked in and out.

e. Access roads for transportation of wastes from entrance to disposal units and for maintenance and monitoring. To assure that roads on the site do not interfere with site closure and stabilization plans, they should be designed so that construction equipment and other anticipated vehicles will not damage monitoring stations or completed disposal areas during normal operational activities. Roads should be of sufficient width and durability that vehicles may be safely operated on the roads without damaging nearby disposal units which are operating or have been closed. Road surfaces should be designed to prevent concentrated infiltration or runoff which would interfere with other design objectives, i.e., minimizing infiltration, providing a stable site surface and establishing a vegetative cover.

f. A repair shop including tools and facilities for maintenance and repair of operating equipment and fabrication, modification, or repair of special devices, equipment, or sampling and testing equipment.

g. Overpack container fabrication and storage areas. This facility may or may not be necessary or desirable, depending on the plan of operations and customer needs.

h. Testing laboratory, including necessary testing equipment and computer facilities for storage, retrieval, plotting, and analysis of test and monitoring data. It is considered important to have these facilities onsite to avoid delays between sampling and testing. In this way, the site manager and his staff can quickly detect any abnormalities or trends that might develop and take action as needed to correct them.

i. A truck wash and decontamination facility is recommended. The waste water must be properly treated and disposed of.

j. Personnel and clothing decontamination facilities should be available.

k. An equipment storage building should be provided.

l. A temporary waste storage area should be available, including unloading facilities, for use in case of temporary shutdown of disposal operations due to inclement weather or during periods of peak waste receipts. This storage area should be designed to minimize contact of rainfall and runoff water with waste packages.

m. Operating equipment, including some or all of the following:

    (1) Pickups and vans for transporting personnel and visitors.

    (2) Trucks and trailers for transporting waste packages, construction materials, and heavy equipment.

    (3) Front end loader/backhoe excavator to remove spoil and place backfill and drainage material.

    (4) Forklift for use in temporary storage operations.

    (5) Drill rig(s) for exploration boreholes, piezometers, wells, and shaft excavation. It may be possible to use the same rig for

shaft excavation if shafts are to be relatively small diameter and shallow.

(6) Mobile crane for placing shaft liner, collar, and waste packages.

(7) The sizes, number required, and even the need for some of the above equipment would be dependent on the operating plan, site conditions, and customer needs.

n. Nominal inventory of spare parts and tools for repairs to vital or emergency equipment.

o. Survey markers and survey equipment.

p. Runoff control features should include components for collection, transport and discharge, as necessary to prevent flooding, ponding, and erosion. Pangburn and Pennifill (1982) have discussed the goals of surface water management and provided guidance for achieving these goals.

Accepted practice for management of surface water at commercial shallow land burial sites has been discussed by Tucker (1983), along with recommendations for improved performance. Tucker discussed methods to maximize surface runoff and to minimize infiltration through the cover.

Some of these recommendations are already being practiced at commercial and DOE disposal sites, and others will probably be adopted as new sites are opened.

These recommendations relate to surface and trench bottom grading practices, proper trench orientation in relation to surface contours, and progressive and sequential trench construction. Establishment of a vegetative cover is also recommended. Differences in conditions and design requirements are noted for arid regions.

Most of these recommended practices would be appropriate for a shaft disposal facility.

Additional measures could be taken to improve surface drainage and cover performance. Most of these measures would add to the operating expenses, but would reduce long-term maintenance.

For example, concrete or soil cement covers such as shown in Figure 10 would reduce the potential for erosion and infiltration.

Rock-filled or paved drainage ditches would also reduce erosion and maintenance problems. Guidelines are given in Tucker's report for evaluating the erosion potential of various drainage ditch profiles and various soil types.

These examples are cited to point out potential improvements, not absolute requirements.

q. Backfill. The functions of backfill are to reduce the potential for subsidence of the cover and to enhance waste isolation by minimizing contact of waste packages with water.

Voids between waste packages can be more easily filled using coarse-grained soil as backfill. However, coarse-grained backfill is more pervious to infiltrating water. Fine-grained soils tend to

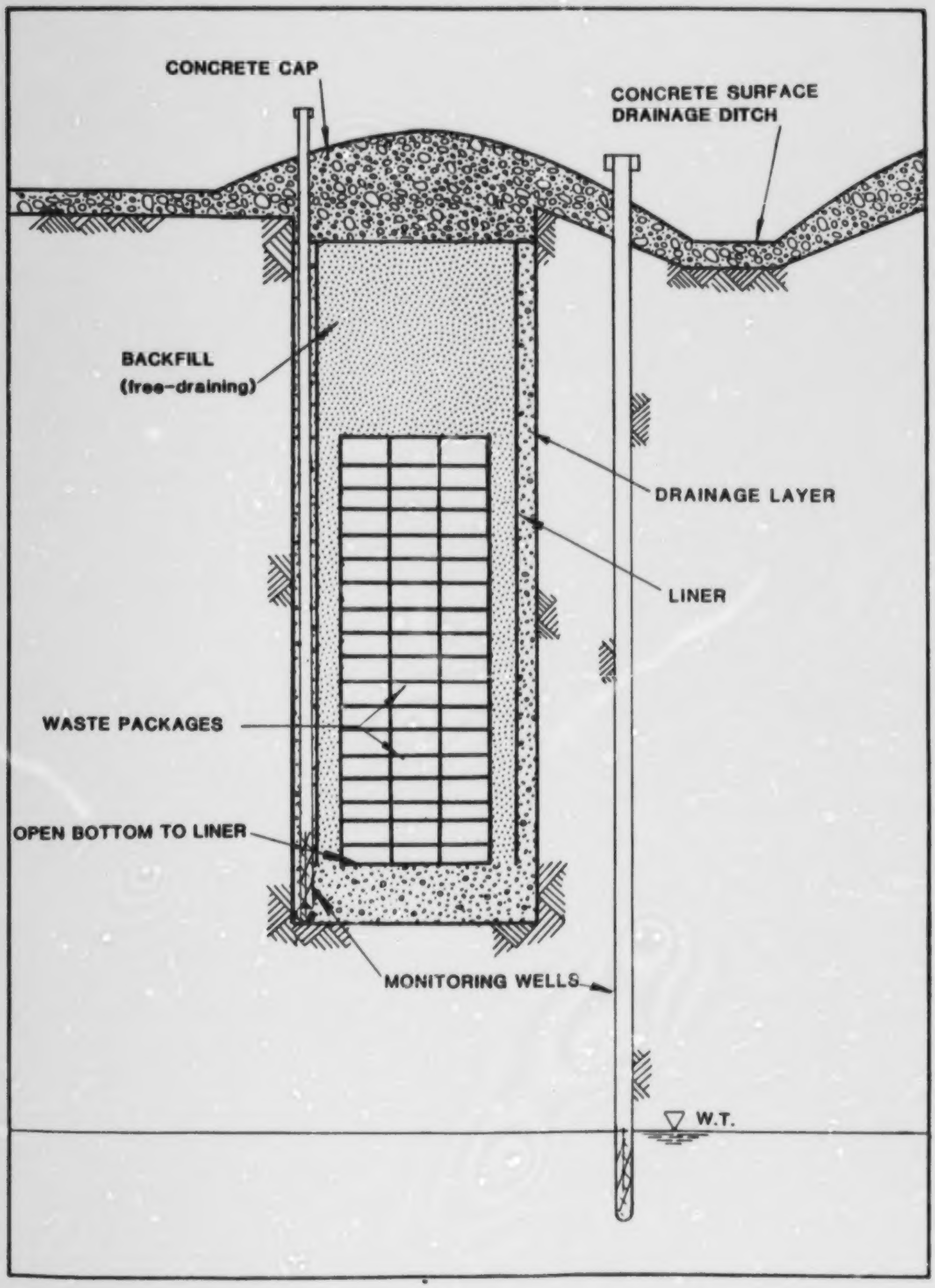

CONCRETE CAP
CONCRETE SURFACE DRAINAGE DITCH
BACKFILL (free-draining)
DRAINAGE LAYER
LINER
WASTE PACKAGES
OPEN BOTTOM TO LINER
MONITORING WELLS
W.T.

Figure 10. Shaft disposal facility for disposal above water table with enhanced performance features including lining, drainage layer, improved backfill, cover, cap, and concrete-lined surface drainage ditch

bridge voids and leave open spaces between waste packages. It is very difficult to achieve compaction of fine-grained soil into voids between packages. Thus consolidation and surface subsidence would cause maintenance problems.

Consequently, it may be necessary or desirable to segregate site deposits or use offsite materials to achieve satisfactory performance. For example, the coarse materials could be used to fill voids between packages and backfill to the top of the shaft. The finer materials would then be used as a cover above the shaft.

The NRC staff (Pangburn and Pennifill, 1982) has recommended that a freely-draining, noncohesive material, such as a clean sand or gravel, be used to fill the spaces beween waste containers. These materials promote rapid movement of water through the disposal unit and minimize the length of time in which water would be available to leach the waste. In addition, if the backfill has a sufficient contrast in permeability to the material in the trench cap, capillary forces may promote unsaturated flow of interstitial water around the disposal unit instead of through it. This is due to the fact that granular soils develop significantly lower suction pressures than fine-grained soils.

Perhaps a better alternative, though more expensive, would be the use of a high slump concrete mix as backfill around the waste packages. Dry bentonite could also be used for this purpose. This material, even with minimal compaction, could provide an effective barrier to prevent infiltrating water from reaching the waste packages for a very long time. Bentonite also reduces radionuclide migration rates because of its low permeability and good adsorption qualities (Muroi and others, 1984; Borgesson, 1982).

r. Quality control testing equipment should include apparatus to sample and test site cast concrete, backfill moisture and density, and waste package integrity.

s. Monitoring devices should include piezometers, wells, water sampling devices, air sampling stations, and weather stations.

Lutton and others (1982a, 1982b, and 1983), in a series of three reports, described the parameters of concern for monitoring a shallow land burial site, test methods, and equipment required to measure and monitor these parameters, and suggested frequency of measurements.

Sedlett and others (1982) have developed a handbook for environmental monitoring of LLW disposal sites.

Cherry and Gillham (1977) present a somewhat different viewpoint for monitoring a shaft disposal facility in which wastes would be buried below the water table and below the zone of weathering. They point out the need to minimize the number of boreholes and wells penetrating from the surface to the hydrogeological unit used for disposal. They suggest a minimal monitoring program of periodic soil and water samples and a high degree of reliance in the ability of site characteristics to ensure long-term isolation of radionuclides from the biosphere.

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The monitoring program extends from the preoperational site investigation program, through the operating period, and for some time after closure. Therefore, the instruments used should be rugged and reliable over extended periods of time. When possible, monitoring locations should be chosen that allow for periodic repair or replacement of monitoring devices as necessary.

t. Shaft drilling equipment. The larger the diameter and depth of the hole, the larger is the required drill rig. The rig must have sufficient power to turn the auger or bit and must have sufficient power and reach to pull the drill string from the hole. Holes may be bored to practically any depth and diameter as long as the rig used can bore through the site soil or rock and the walls are supported or can stand unsupported. However, there are certain practical size and depth constraints. For deep holes in the 10-ft-diam range, the rigs required are quite large and expensive. Figure 1 shows a drill rig used to bore 10 ft-diam shafts in soil. On the other hand, for an operation using smaller diameter shafts in softer soils, the same truck mounted drill rig used for borings and wells could be used for the disposal shafts. A smaller rig such as this is shown in Figure 11. Hard ground slows the drilling rate; auger rigs work best in soft to moderately firm consistency cohesive soils. Boulders are major obstacles to steady, predictable rates of progress. These must be removed by jack hammering and hand loading, a time-consuming and sometimes dangerous task.

u. Shaft collar. The collar could be a thick steel reusable unit to lower operating costs or a less capital intensive alternative such as corrugated metal or fiberglass that could be left in place to act as a structural lining and to retard lateral flow. However, the main collar function is to prevent the hole from caving during construction and operations. Consequently, long-term durability is only of economic concern.

v. Shaft lining. The shaft lining acts as structural reinforcement, as an additional shield to radioactivity and to retard lateral flow. Shaft linings may not always be required, if, for example, the shafts are being sunk in a firm, cohesive low permeability clay above the water table or in sound rock. However, if they are deemed necessary, they should be designed for long-term performance and durability. Good quality control must be maintained during their construction. Lining materials could be cast in place or precast concrete pipe sections, corrugated galvanized steel, or reinforced fiberglass. Precast or premolded liners work well if a drainage layer and monitoring well are to be installed.. First the base of the drainage layer can be placed, the lining installed and temporarily braced, and the monitoring well installed and braced. The drainage blanket material can then be placed in the annulus between the liner and the shaft walls and vibrated to densify it. It may be advisable to pour a short concrete plug inside the bottom of the liner to anchor it against buoyancy or uplift. Otherwise, rainfall and runoff that get into the shaft while it is open could float the lining out. This

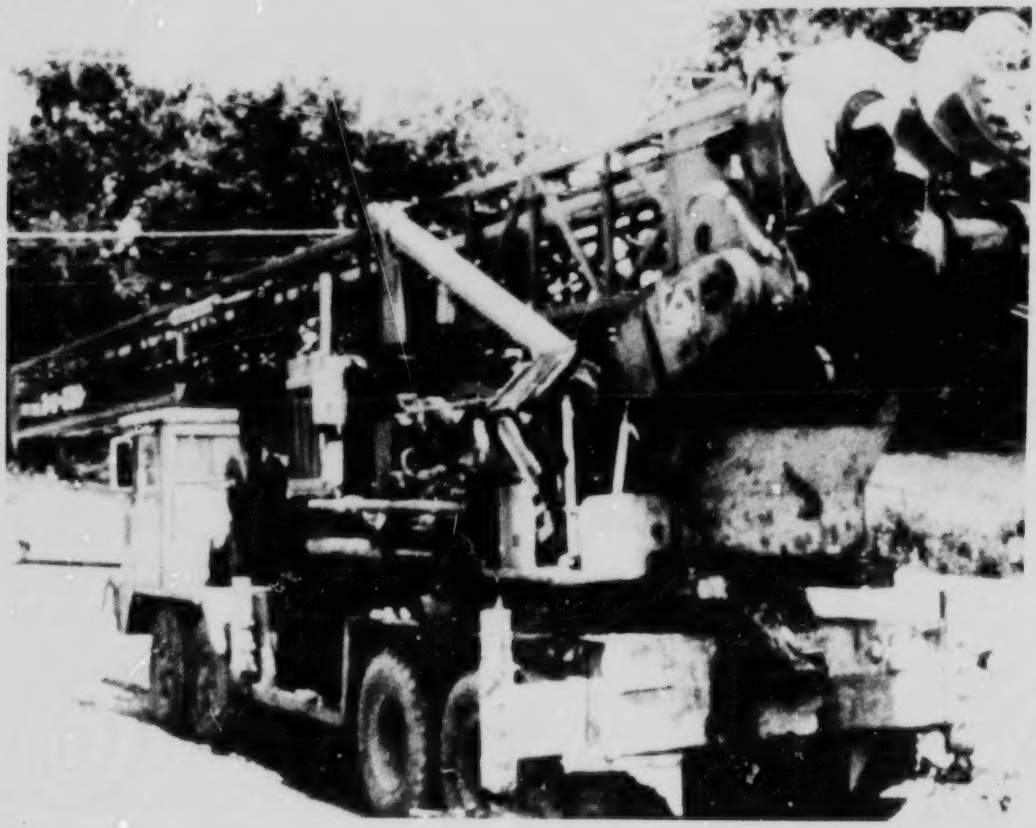

Figure 11. Photograph of auger shaft drill rig

potential problem can also be avoided by leaving the bottom of the shaft lining open to the drainage layer. In this case, the possibility of occurrence of the so called bathtub effect is reduced but the chance that rising water could reach the waste packages from the open bottom is increased.

w. Drainage layer. As was the case with the shaft lining, a drainage layer may not always be required or desirable. Similarly, if it is needed at all, it should be designed and constructed for long-term performance. The drainage layer should extend around the sides and bottom of the shaft and be designed to prevent capillary wicking action inside the shaft. The drainage layer should be designed to prevent excessive fine-grained materials from migrating from the shaft walls into the layer and thereby clogging the drain.

x. Monitoring well and piezometers. In the author's opinion, a monitoring well should be installed at each disposal shaft. Monitoring wells should be installed with the screened portion reaching the bottom of the drainage layer so that any water that collected could be pumped out. This water should be measured, sampled, and analyzed. Piezometers should be installed at each disposal shaft that extend below the zone of fluctuation of the water table to allow periodic checks of water levels and samples to be taken.

y. Special lifting and lowering equipment. Shaft linings and collars can be lowered into the shaft and removed using a mobile crane. However, for emplacing the waste packages, specialized equipment might be safer and more practical. For example a vacuum lift can be used with the crane to pick the waste drums or packages from the truck, lower and stack them into the shaft, and remotely release the packages. This procedure could greatly reduce exposure of workers to radiation risks and also reduce accidents during unloading operations. Various vacuum lift devices are commercially available and are currently used at waste disposal sites, as well as warehouses and container manufacturers. One such unit is shown in Figure 6. It should be pointed out that a square stacking configuration of waste drums, though not the most space efficient, reduces worker exposure and handling times. Any stacking arrangement that uses one central drum surrounded by other drums will require rehandling after unloading the wastes from the trucks before placing them in the disposal shaft.

z. Small compaction equipment. In the author's opinion, it is essential that the backfill be compacted to prevent or minimize subsidence at the surface. Subsidence, if uncorrected, could allow surface water to pond in the subsidence depression and infiltrate to the waste packages. It is equally important to prevent damage to the waste packages during compaction of the backfill. Thus, portable, easily controlled equipment is recommended. As noted in section 2.2, backfill is not compacted at some existing shaft storage sites. Active maintenance is an ongoing concern at these sites. Backfill compaction would significantly reduce this subsidence problem.

2.4 Performance Capabilities

The design, construction, operation, closure, and monitoring of shafts can be accomplished with proven technology and commercially available equipment.

Protection of the general population from releases of radioactivity can be satisfactorily achieved. Hole caps must be carefully designed to insure this protection.

In the absence of significant ground-water movement or infiltration of surface water, slow diffusion of radioactive ions through surrounding soils is probably the dominant mode of radionuclide migration (Cherry and Gillham, 1977; Gillham and Cherry, 1983). This slow diffusion and generally greater disposal depth will help reduce the concentrations of radioactive materials released to the atmosphere at the surface or to the ground water.

Protection of individuals from inadvertent intrusion and prevention of plant and animal intrusion can be achieved through the use of greater disposal depth and thick covers, the use of sealing plugs and caps, and through the use of long lasting surface markers or labels identifying the disposal shafts.

Protection of individuals during operations is achievable through the use of shielded transport casks for high activity wastes. The transfer of the wastes from the transport vehicle to the hole must be carefully executed with the proper equipment, but this operation is routinely and safely done at existing storage sites and presents no significant problems. Also contributing to safety is the fact that no workers must enter the disposal shafts.

If the backfill is reasonably compacted, settlement and hole side wall stability should not be a problem. The top of the holes can be capped slightly above the original grade to minimize infiltration of surface runoff and to allow for some settlement. Surface contours and vegetation could be established to minimize erosion from runoff. If these practices are followed, stability of the disposal site after closure should be achievable and active maintenance should be minimal.

The practical dimensions of a shaft disposal facility are dependent on projected waste volumes, land availability, site characteristics, container sizes, safety, and costs. The limits on diameter are primarily dependent on the capabilities of the drilling equipment. The limits on depth of burial should be based on analysis of soil hydraulic conductivity, the depth to the water table and seasonal fluctuations, and depth to the bedrock. The minimum cover thickness allowed should minimize the possibilities of exposure to humans and animals, either from inadvertent intrusion, burrowing, radionuclide migration through the cover, or root penetration and plant uptake.

The increased depth of disposal in shafts would reduce the amount of water infiltrating the wastes from the surface if the cover and backfill are compacted to prevent cracks from forming. Such cracks could short circuit the cover and backfill's protection and provide preferential flow paths if they occurred.

Stable temperatures and higher pressures at greater depths may reduce the rate of formation of gases and thus reduce their rate of transport to the ground surface.

A high degree of protection from erosion and flooding may be achieved with shafts.

To achieve the desired performance and minimize active maintenance, quality control of waste emplacement, backfilling, and cover construction must ensure that void spaces have been minimized and filled and that the backfill and cover have been compacted. Also, water must be prevented from entering the hole during construction and operations.

In summary, the shaft disposal alternative offers the possibility of satisfactory isolation of the wastes from the ground surface and ground water, and hence satisfactory protection of humans, and barriers to animals and plants.

3. TECHNICAL REQUIREMENTS FOR SHAFT DISPOSAL OF LLW

In this section, the technical requirements thought to be necessary for evaluation of site suitability, design, operations, closure, and monitoring are developed.

The pattern of development used for each section is:

a. First, each existing criterion for near-surface disposal is quoted, including the subparagraph number of 10 CFR 61 Subpart D under which it appears.

b. The criterion is discussed and judged as to its relevance to shaft disposal.

c. A recommendation is made to:

   (1) Retain the criterion as is.

   (2) Not apply the criterion to the evaluation of this alternative, as it is not applicable.

   (3) Modify the criterion to make it applicable to this alternative.

Any recommended modifications to the existing criterion are underlined. Words that are recommended to be deleted are indicated by a dash through each letter. Any departures or changes in recommendations from the position taken in the Task 1 report (Bennett and others, 1984) are noted.

At the end of each section (site suitability, design, operations and closure, and monitoring) technical requirements implied within 10 CFR 61.12 relative to these topics which are not covered by existing criteria or recommended modifications are discussed. Specific criteria in prescriptive language are not given. Rather the points that should be addressed and the reasoning behind them are stated. This method of presentation is thought to be more appropriate than offering specific criteria, as it allows the Commission to consider those issues and develop specific wording that it considers appropriate on a point by point basis.
Alternatively, the NRC may wish to provide regulatory guidance, as appropriate, without changing or adding to the existing criteria.

3.1 Site Suitability

3.1.1 Role of Site Characteristics

The primary emphasis in disposal site suitability is given to the long-term attainment of the performance objectives of 10 CFR Part 61, Subpart C.

Site characteristics should not only facilitate design and construction, but also promote the ease of the operations and closure phases. The primary role of site characteristics, however, will be to promote the stability and isolation of wastes in the event of failure of any system component.

Sole reliance on site characteristics for meeting the performance objectives is not a requirement, recognizing that collective use will be made of site characteristics, design features, operations and closure methods, waste-form management, and institutional controls. Since disposal facilities may be constructed in many different geographical areas, it is anticipated that the sites will reflect a wide range of geologic, hydrologic, meteorologic, climatic, environmental, and socioeconomic conditions. The contribution of site characteristics toward stability and isolation of wastes, therefore, may vary from site to site.

In general, the reliance which can be placed on design features and maintenance tends to decrease with increasing time after closure. Therefore, tradeoffs related to the degree of reliance placed in site characteristics, design features, or methods of facility operation and site closure should be made with the goal of maximizing the long-term contribution toward public health and safety (Siefken and others, 1982).

Site characterization may be defined as a program of investigations and tests, both in the field and laboratory, undertaken to define the site characteristics affecting the isolation of the LLW and long-term stability of disposal sites. Characteristics of the disposal site and surrounding vicinity which must be determined should include, but not necessarily be limited to, the geological, geomechanical, hydrological, meteorological, and climatological characteristics.

3.1.1.1 Geological and Geomechanical Characteristics

A regional geological framework, including the stratigraphy, tectonics, structure, and physiography, must be established for a proposed site. Detailed geologic information, required for site modeling, should be obtained by surface mapping, exploratory boreholes, surficial geophysical surveys, borehole geophysical logging, and test pit excavations.

Geomechanical characteristics of the site soil and rock deposits are required for evaluation, as well as design and analyses. Performance parameters such as the coefficient of consolidation, permeability, cohesion, angle of internal friction, unconfined compressive strength, and deformation modulus should be determined, as appropriate, for the soil and rock types. Index properties, such as water contents, unit weights, Atterberg limits, Standard Penetration Test (SPT) blow counts, cone penetration resistance, particle-size distribution, void ratio, organic content, and Rock Quality Designation (RQD) should be determined for classification, as well as design purposes. Bearing capacity and settlement should be predicted from appropriate soil properties and structural loads and layout.

3.1.1.2 Hydrological Characteristics

Surface water and ground water represent the most significant pathways for potential long-term releases to the general population. Proper characterization of the hydrological conditions requires both site-specific and regional data. Surface water studies should include aerial photography and topographic mapping, as well as the determination of drainage areas, flood flow frequencies, runoff rates, infiltration rates, flow rates, and flow volumes.

To define the hydrological and stratigraphic framework, site characterization studies should be performed to identify and characterize the separate hydrogeologic units underlying the site, including their lithology, thickness, lateral extent, continuity, inclination, areas and modes of recharge and discharge, piezometric levels, hydrochemistry, interrelationship with adjacent hydrogeologic units, and interrelationship with surface water bodies.

The hydrological characteristics of the site should be used to develop flow and transport models with which migration of potential releases may be evaluated. In addition to modeling the surface and subsurface hydrology, ground truth documentation should be obtained by laboratory and field tests. Data collection or sampling points should be established which will not only verify model predictions, but which may continue to be used throughout the design and construction phases and, eventually, for long-term monitoring.

3.1.1.3 Meteorological and Climatological Characteristics

Site meteorological and climatological data are required to determine a water budget, establish the ranges and frequency of occurrence of unusual phenomena, and perform atmospheric dispersion analyses. The NRC staff (Siefken and others, 1982) recommends that an onsite meteorological station should be established and operated a minimum of one year during site characterization to obtain site-specific data. Existing long-term data should be obtained from the National Oceanographic and Atmospheric Administration. The onsite meteorological station should be incorporated into the eventual site monitoring program to verify data used for the evaluation and characterization.

3.1.2 Assessment of Existing Criteria

The existing criteria for assessment of near-surface disposal site suitability are contained in 10 CFR 61 Subpart D, paragraph 61.50.

Criterion 61.50 (a)(1) states: "The purpose of this section is to specify the minimum characteristics a disposal site must have to be acceptable for use as a near-surface disposal facility. The primary emphasis in disposal site suitability is given to isolation of wastes, a matter having long-term impacts, and to disposal site features that ensure that the long-term performance objectives of Subpart C of this part are met, as opposed to short-term convenience or benefits."

Discussion. Disposal of LLW in relatively shallow shafts is similar in many respects to near-surface disposal in trenches. Consequently, most of the features that would make a site suitable for trench disposal would also make a site suitable or desirable for a shaft disposal facility.

The emphasis for site suitability has not changed, nor has the importance of ensuring that long-term performance objectives be met.

Recommendation. This criterion states the goal of all subsequent site suitability criterion. Therefore, the criterion should be retained as is.

Criterion 10 CFR 61.50 (a)(2) states: "The disposal site shall be capable of being characterized, modeled, analyzed, and monitored."

Discussion. This criterion is necessary to ensure that the long-term performance objectives are met. While the wording seems deceptively simple, the underlying issue is not. Many rather clever analytical tools have been developed to model natural systems, e.g., 2-D and 3-D computer simulations for analysis of ground-water movement, and sophisticated analyses of slope stability.

However, all models and analyses depend on sound judgment and reliable input data (strengths, permeability, depth to water table, etc.) to reach correct solutions.

In general, the more variable data are, the less reliable are our inferences and judgments about them. Specifically, the site should be geologically simple so that site characterization, modeling, and analysis are not too complex. The NRC staff (Siefken 1982) has pointed out that models tend to homogenize stratigraphic units and average the hydrologic properties to satisfy assumptions and boundary conditions. Therefore, the site characteristics used as model inputs must vary over a sufficiently narrow range so that the simplified inputs and assumptions are valid. Sedlett and others (1982), Cherry, Grisak, and Jackson (1974), and Cherry and Gilham (1977) have discussed this issue and indicated that monitoring to measure the necessary site characteristics is much more complex and less reliable for geologically complex sites. Sedlett indicated that it may be impossible to get adequate, reliable data from sites underlain by fractured rock. Even sophisticated, expensive site investigations only sample a small fraction of the subsurface, so extrapolation over wide areas at highly variable sites is unreliable.

Gilham and Cherry (1983) recommended that in Canada, wastes should be disposed of below the zone of chemical and physical weathering, primarily because of the higher ground-water transport rates and the problems associated with predicting transport rates in weathered, fractured upper zones.

Simply put, the more uniform the site and the natural processes occurring on it, the less complex and costly the site investigation may be, and the more reliable predictions may be.

Recommendation. This criterion should be retained as is.

Criterion 61.50 (a)(3) states: "Within the region or state where the facility is to be located, a disposal site should be selected so that projected population growth and future developments are not likely to affect the ability of the disposal facility to meet the performance objectives of Subpart C of this part.

Discussion. The objectives of this criterion are to minimize the risks of exposure of the general population to releases of radioactivity and to minimize the risks of inadvertent intrusion. Census data and urban planning studies should be analyzed to develop site-specific population and development projections. However, it is unlikely that the data and projections from existing planning studies would be reliable for long-term projections. Most forecasts are relatively short term (50 years or less). Extrapolation of short-term projections to 100 to 500 years into the future is speculative at best. Therefore, while the goal of the criterion is a valid one, it may be quite difficult to implement reliably.

Recommendation. The criterion should be retained as is.

Criterion 10 CFR 61.50 (a)(4) states: "Areas must be avoided having known natural resources which, if exploited, would result in failure to meet the performance objectives of Subpart C of this part."

Discussion. The goal of this criterion is to avoid the possibility of compromising site integrity caused by future exploration or exploitation of the natural resources adjacent to or underlying the disposal site. An example would be deep borings for oil exploration. A less obvious example might be a deep water well. Such wells, if pumped at rates much higher than the ground-water recharge rates, can cause surface subsidence and cracking of the surface. This phenomenon is a serious problem in the arid southwestern U. S.

Recommendation. The criterion should be retained as is. The goal of the criterion is sound. Further, practical application of the criterion is not likely to preclude or significantly limit the selection of suitable sites within a given region or state.

Criterion 10 CFR 61.50 (a)(5) states: "The disposal site must be generally well drained and free of areas of flooding or frequent ponding. Waste disposal shall not take place in a 100-year floodplain, coastal high-hazard area or wetland, as defined in Executive Order 11988, "Floodplain Management Guidelines."

Discussion. The above criterion has both legal and technical aspects.

The desirability of a well-drained site free of areas of flooding or frequent ponding can be readily understood for the operations phase. Open, flooded shafts would have to be pumped dry. Shaft walls might collapse. Shaft liners or even waste packages might float out of the shafts. Equipment could be damaged or immobilized, making it impossible to take damage prevention or remedial measures.

The probability of occurrence and severity of the above problems can be estimated, based on the frequency and extent of a flood event at a specific site.

The second part of the criterion, which prescribes avoidance of legally defined flood prone areas is technically achievable using existing maps, rainfall and runoff data, and appropriate hydrological models.

Recommendation. The criterion should be retained as is.

Criterion 10 CFR 61.50 (a)(6) states: "Upstream drainage areas must be minimized to decrease the amount of runoff which could erode or inundate waste disposal units."

Discussion. It is the author's opinion that unlike the previous criterion which prescribed avoidance of legally defined flood-prone lowland areas, the above criterion has as its primary goal, the prevention or minimization of damage from flash flood situations. This situation is more likely in areas of higher topographic relief.

The criterion, therefore, implies that the disposal units should be located on high ground, i.e., the ridgetops and plateaus, but protected valleys or relatively flat lands are not excluded. This requirement is technically sound. As an added benefit, in humid regions it is quite possible that drilling of the disposal shafts on high ground would allow deeper shafts to be used because of the greater depth to the water table, or a greater thickness of soil or rock buffer zone could be maintained between the shaft bottom and the water table.

Recommendation. The criterion should be retained as is.

Criterion 10 CFR 61.50 (a)(7) states: "The disposal site must provide sufficient depth to the water table that ground-water intrusion, perennial or otherwise, into the waste will not occur. The Commission will consider an exception to this requirement to allow disposal below the water table if it can be conclusively shown that disposal site characteristics will result in molecular diffusion being the predominant means of radionuclide movement and the rate of movement will result in the performance objectives of Subpart C of this part being met. In no case will waste disposal be permitted in the zone of fluctuation of the water table."

Discussion. The goal of this requirement is to avoid contact of waste packages and ground water. Ground water is considered to be the major pathway of release in humid areas. Contact of water and waste packages also hastens the rate of package deterioration and radionuclide migration. The criterion does not specify the depth between the water table and the disposal unit. This depth must be determined from measurement and analysis of site characteristics. These characteristics include the coefficient of permeability, the degree of homogeneity of the site soil and rock deposits, presence of preferential flow paths, and the degree of fluctuation of the water table. The impacts of present and projected land uses on the regional water table should not be overlooked.

Siefken (1982) has discussed the conditions that should be met for conclusive evidence of molecular diffusion being the predominant means of radionuclide movement. He suggested the use of age-dating of ground water as one method for this purpose and discouraged the use of more common methods such as pumping tests or pressure injection tests as being inapplicable for very tight formations.

In the author's opinion, it is conceivable that a suitable disposal site could be located such that disposal below the water table would pose no higher risks and perhaps lower risks than disposal above the water table. However, the evidence required to demonstrate this would have to be quite reliable to withstand the intense scrutiny it would receive.

Such evidence would be expensive to obtain and might still prove inconclusive. Ground-water age dating at Stripa mine in Sweden during the Swedish American Cooperative Program (Fritz, Barker, and Gale, 1979) showed the ground water to be a mixture of water from different origins and time periods. Since geological processes had occurred to alter flow paths and rates of movement (as well as origins), several questions could not be answered by age dating alone. Much additional testing and analyses, using pioneering methods and equipment, were required.

The Stripa mine is in a geologically complex region. Similar areas in the U. S. may not be considered as typical disposal site candidates, because of this complexity. In fact Stripa mine is not a candidate repository site. However, this case illustrates the difficulty that might be encountered in conclusively demonstrating that molecular diffusion is the predominant means of radionuclide migration.

On the other hand, Cherry and Gillham (1977) convincingly argue that molecular diffusion can be demonstrated conclusively for certain very low permeability thick clay deposits below the zone of weathering and that waste disposal in such deposits below any aquifers used for water supply offers the best option for long-term waste isolation in Canada. They offered three hydrogeologic criteria to support site suitability. The criteria are that the site should:

a. Be geomorphically and seismically stable.

b. Be such that adequate burial space can be created at a significant depth below the level of active water table fluctuation in a zone where the rate of hydraulic flow of ground water is negligible in comparison to rates of molecular diffusion.

c. Be such that the burial space can be located in a position within the regional ground-water flow system that, in the event that radionuclide leakage occurs, would prevent contamination of aquifers used for water supply and which would tend to prevent migration of radionuclides into the biosphere.

Diffusion-controlled transport zones were judged to be acceptable because diffusion is an extremely slow process, with radionuclide concentration as its driving mechanism. This disposal option was judged to be much more desirable than burial in or near the zone of ground-water fluctuation. They suggested age dating of ground water by measuring the distribution of natural isotopes such as ^{3}H, ^{18}O, and ^{14}C to determine whether fractures present significant transport pathways. They did not, however, rule out or discourage disposal above the water table and zone of fluctuation. They suggested a minimum distance of 6 to 8 meters above the average water table depth. However, their attempts to apply this criterion and other important technical considerations led them to conclude that searches for suitable sites for disposal above the water table were futile in southern Canada.

In summary, the prime goal of the criterion to minimize contact of moving water with wastes can be achieved either by maintaining a sufficient distance between the wastes and moving ground water or by disposal in very low permeability deposits in the regional ground-water systems.

Recommendation. The criterion is applicable to disposal of LLW in shafts and should be retained as is. Since the ground-water pathway is so important in the assessment of disposal site performance in humid regions, this criterion is considered to be a crucial test for site suitability.

Criterion 10 CFR 61.50 (a)(8) states: "The hydrogeologic unit used for disposal shall not discharge ground water to the surface within the disposal site."

Discussion. Location of a disposal unit in a formation that discharged ground water to the surface within or even near the site should be considered unsafe and unnecessary. It is relatively simple to uncover evidence of springs early in the site investigation. Such occurrences should be grounds for exclusion of that particular site from further consideration.

Recommendation. The criterion should be retained as is.

Criterion 10 CFR 61.50 (a)(9) states: "Areas must be avoided where tectonic processes such as faulting, folding, seismic activity, or vulcanism may occur with such frequency and extent to significantly affect the ability of the disposal site to meet the performance objectives of Subpart C of this part, or may preclude defensible modeling and prediction of long-term impacts."

Discussion. The performance objectives to which this criterion refer are equally applicable to any LLW disposal alternative. However, the degree to which occurrence of a tectonic process might impair disposal site performance would vary significantly for different disposal concepts.

The vulnerability of shaft disposal units with linings designed to resist damage from foreseeable seismic events, specifically earthquake generated forces, is substantially less than any disposal concept relying heavily on subsurface placement of soil for satisfactory performance. Unlined shafts would be subject to the same comparable risks as trenches. The NRC staff (Siefken and others, 1982) believes that more emphasis should be placed on suitable site characteristics than on engineering features to overcome site problems. The author shares this opinion but believes that there are available engineering design solutions to minimize adverse impacts from predictable design basis natural events, such as the use of plastically deformable backfill materials. Inherent in any earthquake resistant design is the necessity to quantify potential accelerations and frequency of occurrence.

Recommendation. The criterion should be retained as is. The goal is technically sound and can be implemented without eliminating significant areas that would otherwise be suitable.

Criterion 10 CFR 61.50 (a)(10) states: "Areas must be avoided where surface geologic processes such as mass wasting, erosion, slumping, landsliding, or weathering occur with such frequency and extent to significantly affect the ability of the disposal site to meet the performance objectives of Subpart C of this part, or may preclude defensible modeling and prediction of long-term impacts."

Discussion. The goal of this criterion is valid. Serious erosion could uncover the waste packages if left uncorrected. Slumping soils and landslides could crack or destroy shaft linings, drainage layers, or monitoring wells. Weathering of site geologic materials can result in swelling, increased erosion, and significant changes in infiltration rates. Areas undergoing rapid geological processes can usually be identified during the screening process through analysis of aerial photographs taken a few years to tens of years apart. Such areas can be eliminated at this stage without seriously limiting the availability of suitable sites within a state or region.

Recommendation. The criterion should be retained as is. This recommendation differs from the position stated in the Task 1 report. The recommended modifications stated in the Task 1 report are discussed under the "Suggested Additional Technical Considerations" section of this report. These issues are not properly described as surface geological processes.

Criterion 10 CFR 61.50 (a)(11) states: "The disposal site must not be located where nearby facilities or activities could adversely impact the ability of the site to meet the performance objectives of Subpart C of this part or significantly mask the environmental monitoring program."

Discussion. This requirement is generally applicable to any LLW disposal facility. It does not preclude selection of a disposal site near other facilities. It does require an assessment of the potential adverse impacts of such a decision. This assessment can only be made on a site specific basis but examples of activities that could impair the site's ability to meet the performance objectives include water treatment plants, dams for seasonal flood control, water supply, or power generation, and open pit or underground mines. The site should not be near high traffic highways, railroads, or near chemical processing industries.

Recommendation. The criterion should be retained as is. Because of the site specific nature of this requirement, the criterion must be and is general in its wording.

3.1.3 Suggested Additional Technical Considerations

Additional technical considerations for demonstrating site suitability should include requirements to determine the existence and potential adverse impacts of dispersive soils, liquefiable soils, corrosive soils, expansive soils, karstic or cavernous areas and areas of land subsidence at a potential disposal site.

The potential problems caused by occurrence of such deposits are discussed below.

3.1.3.1 Dispersive Soils

The occurrence of dispersive soil deposits in or near the geohydrologic unit used for disposal can result in accelerated erosion, piping, and collapse of the surface.

Pinhole erosion tests can provide evidence of the susceptibility of soils to dispersion (Sherard and others, 1977). High percentage (greater than 60 percent) of sodium in total dissolved salts is also an indicator of dispersive clays. Dispersive soils cannot be identified by conventional index tests such as Atterberg limits or particle size distribution (Perry, 1979). Visual inspection of cut slopes and embankments can uncover dispersive soils problems. Visual inspection is not very helpful for undisturbed sites because dispersive clays are usually not present in topsoil due to the process of eluviation (movement of clay particles downward in the soil profile). Therefore natural deposits may show little or no evidence from surface appearance that the underlying soil may be dispersive. The piping channels that develop in the underlying soil can be obscured by the vegetative cover and bridging of the topsoil deposit. Eventually, this top layer will collapse into the hole as erosion damage progresses.

In excavated slopes and man-made embankments the dispersive characteristics are more readily observable. Excavated slopes in dispersive clays exhibit rill erosion, surface cracking, and vertical erosion tunnels resembling badlands topography (Perry, 1979). The photographs in Figure 12 show these characteristics.

Embankments constructed of dispersive clays, even with good vegetative cover, also develop rainfall erosion tunnels called cave-ins or jugs. In the author's opinion, the primary risk to disposal shafts constructed in dispersive soil is from piping erosion. If the backfill placed around the waste packages is not properly compacted, interconnected cracks and voids could provide preferential paths for infiltrating water. These paths could become much larger with time as water erodes the cracks further. Eventually, the shaft cover could collapse into the shaft, requiring repair.

If the infiltrating water exits through a shrinkage crack or pipe along the side slope of a ridge, the erosion could lead to local instability of the slope and ultimately to failure.

Measures are available to avoid problems if the dispersive nature of the soil is recognized before construction. For example, sand filters can be used to seal and safely control leaks in dispersive clays.

Lime treatment has also proved effective in reducing tunnel erosion in dispersive clay dams (Forsythe, 1977; Phillips, 1977; and Rosewell, 1977). The calcium in lime is believed to result in a significant reduction in shrinkage and a lower percentage of exchangeable sodium (and a higher percentage of exchangeable calcium) actually going into solution, thereby reducing the dispersive erosion.

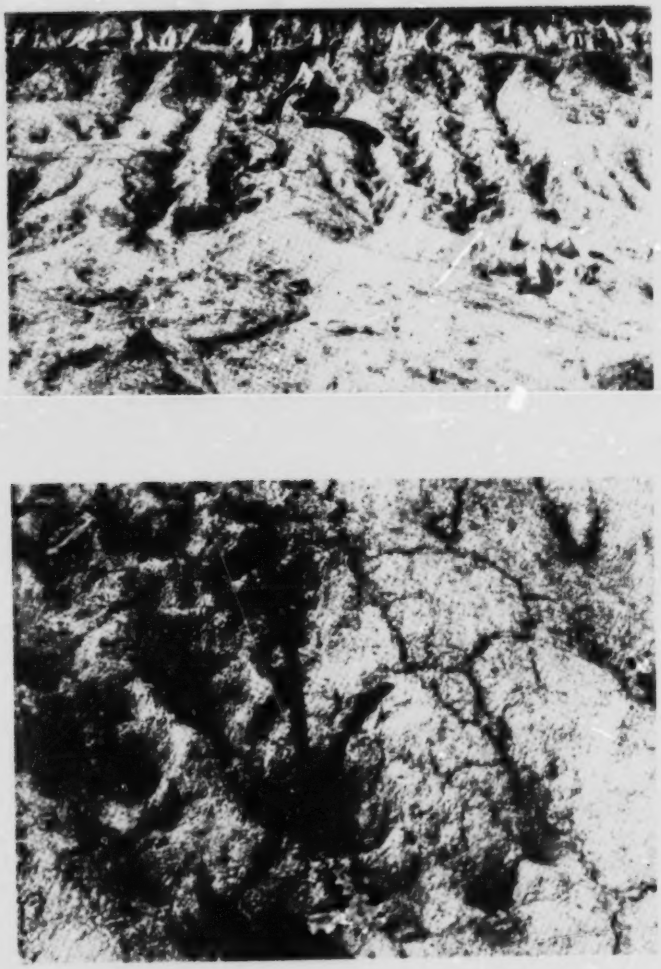

Figure 12. Excavated slope in dispersive clay. Note erosion gullies and piping channels. (Source: Perry, 1979)

3.1.3.2 Corrosive Soils

The occurrence of corrosive soils in humid areas could result in deterioration of disposal unit barriers, e.g., shaft lining, drains, and waste packages. The potential risk from corrosive soils is much smaller in arid regions. Chemical analyses can be used to determine whether a potential problem exists. If so, design and construction measures can be implemented to reduce the impact such as the use of sulfate resistant concrete. In the author's opinion, otherwise suitable sites should not be disqualified on the basis of occurrence of corrosive soils alone.

3.1.3.3 Solution Cavities

Solution cavities are formed in carbonate and sulfate rocks such as limestone, dolomite, marble, and gypsum by the action of slowly moving ground water that dissolves the rock to form tunnels and caves. Most of the caves in the world, including the largest, are of this type. Disposal in hydrogeologic units above carbonate formations that are actively being dissolved should be avoided. Solution cavities can result in collapse of overlying strata used for disposal or which serve as aquicludes.

The occurrence of solution cavities can also result in significant unpredictable alteration of ground-water seepage patterns and quantities which would preclude reliable modelling.

Because of their discrete locations, the probability of locating solution cavities through normal site investigations is low. Geophysical methods have been successful in some cases. With borings, it is literally a hit or miss situation. Obviously, the probability of missing an existing cavity is higher than that of hitting it.

Even if they are reliably located, solution caverns must be grouted to fill the voids. It is costly and difficult to fill completely all voids and impossible to ensure that solutioning will not continue adjacent to the grouted interface.

Regional geological data can provide general evidence to indicate the occurrence, depth, and lateral extent of known karstic formations. These areas should in general be avoided.

3.1.3.4 Liquefiable Soils

Liquefaction of sand deposits has caused extensive damage in numerous seismically active areas of the world, e.g., Japan, Alaska, and California. Less publicized cases of liquefaction of sensitive clays have also caused extensive damage in Norway where marine deposits have liquefied after only minor disturbances. These occurrences were preceded by leaching of salts in the clay by ground water moving downward from mountainous areas to the sea. These clays lose strength as the salts are removed, and in many locations near the sea, a state of near equilibrium exists. Even minor disturbances, such as excavating a building foundation or farm pond, have been known to initiate liquefaction of these deposits. Once started, wide areas can be progressively affected.

More common incidences of liquefaction can be observed along many streams and rivers after prolonged high water conditions. The water level in the stream drops faster than the water table in the stream banks, leading to instability and failure. Not all such incidences can be properly called liquefaction but many are.

The potential risk to LLW disposal facilities from liquefaction is small because most sites with liquefiable deposits have other characteristics that make them undesirable. For example, the site may be near a coastal high hazard area or soil permeability may be too high.

The main danger would be the failure to recognize the liquefaction potential of deposits above or below the hydrogeological unit used for disposal.

3.1.3.5 Expansive Soils

Volume change of expansive soil subgrades resulting from moisture variations frequently cause severe pavement damage. Highways constructed in the Southwest, Western Mountain, Central Plains, and Southeast geographical areas are particularly susceptible to this type of damage.

A 1972 survey (Lamb and Hanna, 1973) of all the 50 states, Puerto Rico, and the District of Columbia indicated that 36 states have expansive soils. Expansive soils occur so extensively within parts of the US that alteration of highway routes to avoid the material is virtually impossible.

The annual cost of damage to streets and highways caused by expansive soils was estimated in 1973 to exceed $1.14 billion (Jones and Holtz, 1973).

Additional damage to slab on grade buildings was not estimated but was and is substantial. Although this damage is of much concern to state and Federal highway officials and local building officials, expansive clay problems do not occur in every state. Likewise, problems do not occur uniformly over areas in which expansive soils are found. The key geological factors in determining a geologic units' expansive nature or "swell potential" are clay mineralogy and amount of clay or shale within a geologic unit. Clay mineralogy, specifically montmorillonite content, can be used to estimate the degree of expansiveness, whereas the frequency of occurrence can be related to the amount of clay or shale in the geologic unit (Snethen, 1979a, 1979b).

One other essential factor that determines whether expansion actually occurs is the availability of water. Without water the soil will not swell. Likewise, if water is available year round, the soil will swell to its full potential under existing loading conditions and no further volume change will occur.

Consequently, the problems caused by expansive soils occur primarily near the surface within the zone of seasonal soil moisture changes. Damage usually takes the form of buckled, warped, and heaved slabs, cracked masonry walls, and general distortion of the structure. For the case of engineered shaft disposal facilities, damage is likely to occur if concrete linings are cast in direct contact with expansive clays.

Methods are available to minimize or prevent damage from expansive soils. However, all the engineering fixes have two things in common. They rely on discovery of the expansive nature of the soil before construction and they add to the construction cost.

The Federal Highway Adminstration has published a series of reports describing research conducted to identify problem areas within the US and to develop remedies where feasible (Snethen et al., 1975; Patrick and Snethen, 1976; Snethen, Johnson and Patrick, 1977a, 1977b; Snethen, 1979a, 1979b). These reports describe methods to characterize the potential for volume change, and provide maps showing the occurrence and distribution of expansive soils in the US. Methods are also recommended for minimizing damage from such soils.

3.1.3.6 Land Subsidence

Subsidence is caused by densification of earth materials, collapse of subsurface cavities, plastic outflow of weak materials, and regional downwarps. There are several causes of densification of earth materials. They are withdrawal of ground water or petroleum, irrigation of old mudflows, vibration of granular materials, densification of deltaic deposits, decomposition of organic materials in swamp deposits, artificial compaction of fills and embankments, and surcharging.

Collapse of subsurface cavities may occur in karst topography or because of previous mining activities.

Examples of plastic outflow of weak materials are in fill above peat bogs and recent lake deposits.

Regional downwarps are large scale subsidence basins and are caused by tectonic, glacial or volcanic activity.

Subsidence is a gravity dominated movement so its principle movement is vertical, but there is always lateral strain associated with subsidence, which could cause serious damage to engineered disposal units.

In some areas land subsidence has progressed to the point of equilibrium under existing conditions and any further movement would be relatively insignificant, unless the driving forces changed, such as increased well pumping. Equilibrium would have to be established for the site to be suitable. Subsidence caused by underground cavities can be reduced by grouting the cavities. However, this is an expensive operation and is not recommended if the site can be avoided.

Regional geological data should be carefully examined to identify any areas of possible subsidence and records of any previous mining, oil drilling, or substantial ground water use practices should be investigated. These areas should be avoided if evidence of significant ongoing subsidence is found.

3.2 Design

3.2.1 Role of Design Features

The role of design features is to complement the natural site characteristics at the disposal site. The degree of reliance that must be placed in the design features will vary from site to site and even within a site. Design features should not be viewed as a means to overcome a site deficiency, unless it can be shown that the design feature will be effective over the entire time period of concern. Rather the design features should enhance or improve the performance of a site already deemed to be satisfactory.

Design features include all the components, equipment, and facilities, other than the land itself, used for waste management and disposal at the site. One goal of the design should be to minimize the potential conflicts between construction, operations, and closure activities to ensure compatibility while providing for efficient land use.

Specific features and components were discussed previously.

3.2.2 Assessment of Existing Criteria

The existing criteria for assessment of near-surface disposal site design are contained in 10 CFR 61 Subpart D, paragraph 61.51. Six technical requirements are listed under subparagraph 61.51(a). Subparagraph 61.51(b) is reserved for disposal site design other than near-surface disposal. This organization is common to the sections on site suitability and operations and closure.

The criteria are considered one at a time in the following paragraphs. Additional technical considerations that should be addressed are discussed at the end of the section.

Criterion 10 CFR 61.51 (a)(1) states: "Site design features must be directed toward long-term isolation and avoidance of the need for continuing active maintenance after site closure."

Discussion. The intent of this requirement is technically sound and desirable. Features and components of a shaft disposal facility that could enhance long-term isolation of wastes and minimize the need for continuing active maintenance have been discussed in the preceding section of this report. Certainly, others might be applicable for specific conditions.

One feature that is not within the scope of site design or this study but which could improve long-term performance is improved waste package design. Many such improvements have been suggested in the literature to enhance the stability of the package and reduce the potential for contact of water with wastes.

These improvements range from embedment of the wastes in bitumen or concrete inside drums to the use of high integrity containers (Schmidt and others, 1984) to reusable overpacks, such as proposed by Miskimin and Cossel (1983).

Waste form and characteristics are also outside the scope of this study, but certainly will require attention to achieve cost effective, long-term satisfaction of performance objectives using this or any other alternative.

Other features which are within the scope of site design features and this study are use of improved backfill, cover and cap, improved surface drainage features, and use of a shaft lining and drainage layer where appropriate. Each of these features was discussed in the preceding section of this report.

Recommendation. The criterion should be retained as is.

Criterion 10 CFR 61.51 (a)(2) states: "The disposal site design and operation must be compatible with the disposal site closure and stabilization plan and lead to disposal site closure that provides reasonable assurance that the performance objectives of Subpart C of this part will be met."

Discussion. The criterion is directly applicable to the shaft disposal method. Since this alternative contains multiple individual disposal units associated with a facility, the operations and closure of individual disposal units must be compatible with the site closure and stabilization plan.

This point has been considered and discussed in relation to shallow land burial by Tucker (1983), and by the NRC staff (Siefken and others, 1982; Pangburn and Pennefill, 1982). No conflicts or differences in design philosophy should occur between shallow land burial or shaft disposal.

However, while this point may seem to be an obvious requirement, i.e., if the site design, operations, and closure are compatible then the design, operations, and closure of individual disposal units must also be compatible, this may not always be the case.

For example, at the DOE's Savannah River Plant, a greater confinement disposal demonstration, described in the previous section of this report, is being conducted (Cook, 1984; Towler, Cook, and Peterson, 1983). At this site the water table is relatively shallow, which limits the shaft depth to about 30 ft.

The site operator plans to dispose of wastes in the bottom 20 ft and backfill 10 ft to the surface. The shafts will be laid out in a rectangular grid pattern with 10 shafts to a side for 80 to 100 shafts. It is estimated that these shafts will hold about 6 years' waste receipts.

When all the shafts have been filled, the operator plans to add an 8-ft fill over the entire area as extra shielding. Because of the close spacing of the shafts and the length of time from start to finish of operations, this extra shielding will not be placed over some of the wastes until about 6 yrs have elapsed from the time of emplacement.

If the extra shielding provided by the fill is needed at all, it is reasonable to assume that it should be placed as soon as possible after waste emplacement.

Therefore, it is believed that a progressive fill operation would be preferable. To do so, however, would require wider spacing of the shafts or use of a retaining wall so that fill operations would not interfere with active disposal operations.

This discussion is not meant to be critical of the site operator or the DOE, but is meant simply to point out the need to consider and plan for compatibility among design, operations, and closure of the individual disposal units, as well as the overall site.

Other examples could be cited, such as the French method of backfilling completed tumuli at their earth mounded bunker disposal facility. Backfill is not placed progressively. Rather the backfill is placed after completing waste emplacement, which may take up to 1 year. This practice means that the waste packages are exposed to the atmosphere and workers are exposed to extra risks during the early, perhaps most critical time period. The risks are largely offset by their extensive use of concrete embedment and waste packaging.

Therefore, although the criterion is judged to be directly applicable, it is recommended that due consideration be given to the compatibility of the design, operation, and closure of individual units, as well as the overall site.

Recommendation. The criterion should be retained as is.

Criterion 10 CFR 61.51 (a)(3) states: "The disposal site must be designed to complement and improve, where appropriate, the ability of the disposal site's natural characteristics to assure that the performance objectives of Subpart C of this part will be met."

Discussion. This criterion is directly applicable to any alternative disposal method, including shafts. In fact, the primary reason for considering any engineered facility for LLW disposal is that it may complement and improve the ability of the disposal site to meet the performance objectives.

Methods and features which could be used to enhance the disposal site's natural characteristics have been discussed in the preceding section of this report.

Recommendation. This criterion should be retained as is.

Criterion 10 CFR 61.51 (a)(4) states: "Covers must be designed to minimize to the extent practicable water infiltration, to direct percolating or surface water away from the disposed waste, and to resist degradation by surface geologic processes and biotic activity."

Discussion. This requirement is vital to satisfactory long-term performance of a shaft disposal facility. Again, methods and components which could be used to enhance cover performance have been discussed in the preceding section. These include the use of shaft liners, drainage layers, pumpable wells, and improved backfill and cover materials. Temporary covers were also recommended to minimize the possibility of runoff and rainfall entering the shaft.

Recommendation. The criterion should be retained as is.

Criterion 10 CFR 61.51 (a)(5) states: "Surface features must direct surface water drainage away from disposal units at velocities and gradients which will not result in erosion that will require ongoing active maintenance in the future."

Discussion. The objective of this requirement is valid. Methods and features for enhancing surface drainage and minimizing erosion and resulting maintenance have been suggested in previous sections of this report. Tucker (1983) also recommends surface grading practices to minimize this problem. He also provides guidance on susceptibility of various soils to erosion and recommends various surface ditch profiles and slopes for reducing erosion of the drain soils.

The primary methods for minimizing erosion are to limit the area over which runoff flows, provide gentle slopes, and channel the runoff into drainage ditches which may be sodded or covered by concrete or other materials to protect them.

Recommendation. The criterion should be retained as is.

Criterion 10 CFR 61.51 (a)(6) states: "The disposal site must be designed to minimize to the extent practicable the contact of water with waste during storage, the contact of standing water with waste during disposal, and the contact of percolating or standing water with wastes after disposal."

Discussion. Again this requirement is valid and achievable. The risk of each of the potential cases of contact of water with wastes can be minimized. Temporary storage areas should be sloped and covered with roofs or temporary storage times should be as short as possible. If temporary shaft covers, drainage layers, and pumpable wells are used, as recommended, the contact of standing water with wastes during disposal should be minimal. Disposal operations should cease during rain and snow storms. If use of satisfactory backfill and cover materials and construction methods are adhered to, the contact of infiltrating water should be minimized.

Recommendation. The criterion should be retained as is.

3.2.3 Suggested Additional Technical Considerations

No specific supplemental criteria are thought to be necessary for shaft disposal site design.

However, the need to plan for individual disposal unit closure, as well as site closure, as discussed under 61.51 (a)(2) should be considered.

In addition, referring back to Site Suitability criterion 61.50 (a)(7), a disposal plan that would place waste packages below the water table will require a considerably different design philosophy than a disposal facility above the water table.

The differences in design requirements will extend from the data to be obtained from the site investigation to the design and construction of components. Operations and closure and especially monitoring methods would be quite different. For example, ground-water aging will be a vital part of the site investigation program. The number of boreholes penetrating through the hydrogeological unit used for disposal should be minimized and these should be plugged with bentonite or other suitable sealing material, after obtaining needed samples to prevent short circuiting of the low permeability disposal unit. Drainage layers would serve no purpose and should not be used with below water table disposal.

Additional design considerations have been addressed in the NRC Technical Position Paper on Near Surface Disposal Facility Design and Operation (Pangburn and Pennifill, 1982). Many of the considerations presented are equally applicable to shaft disposal of LLW.

3.3 Operations and Closure

3.3.1 Importance of Well Planned and Executed Operations and Closure Strategy

The main points to consider in planning for operations and closure of any LLW disposal facility are:

(1) Worker safety with respect to radiological hazards and hazards associated with excavation, construction, and maintenance of the site facilities.

(2) Compatibility of activities to minimize interferences among construction, operations, monitoring, and temporary and final closure.

(3) Avoidance of activities that would lead to long term active maintenance problems.

(4) Records management and quality control and assurance.

(5) Maintenance of a buffer zone of sufficient lateral and vertical extent such that sufficient space and time would be available to carry out remedial actions should they be required. The remedial action plan should be keyed to minimizing off-site releases of radionuclides during the period of significant hazard.

(6) Efficient land use.

The 11 existing criteria for evaluation of land disposal facility operation and disposal site closure are listed under 10 CFR 61 Subpart D, paragraph 61.52.

3.3.2 Assessment of Existing Criteria

As was done in the previous sections for site suitability and design, each criterion is listed, discussed, and a recommendation is then made to retain the criterion as is, modify the criterion, or not apply the criterion in the evaluation of this alternative. Additional technical considerations are discussed at the end of this section.

Criterion 10 CFR 61.52 (a)(1) states: "Wastes designated as Class A pursuant to 10 CFR 61.55, must be segregated from other wastes by placing in disposal units which are sufficiently separated from disposal units for the other waste classes so that any interaction between Class A wastes and other wastes will not result in the failure to meet the performance objectives in Subpart C of this Part. This segregation is not necessary for Class A wastes if they meet the stability requirements in 10 CFR 61.56(b) of this part."

Discussion. The rationale behind this requirement is that comingling of structurally unstable Class A wastes with Class B and Class C wastes could lead to differential settlement of the waste packages and the disposal unit cover. Significant differential settlement would, in turn, lead to cracking of the cover and significant infiltration into the disposal unit. Since the potential risks are high the practice should be avoided. Class A wastes should be disposed of in separate disposal units or should be stabilized before disposal in the same disposal units as B and C wastes. Stabilization and closure of disposal units in which only stable wastes are disposed can be accomplished soon after the units have been filled because long-term subsidence will be minimized (if backfill is properly compacted).

Stabilization and closure of units in which unstable Class A wastes are disposed may not be possible until several years have passed. These disposal units will require a higher level of ongoing maintenance during this time. However, since Class A wastes are wastes of low activity and relatively short half lives, their radiological hazard is low and should be below levels of concern before the end of the institutional control period. Even so, disposal units for segregated Class A (unstable) wastes should be separated by a sufficient distance from other disposal units so that subsidence and infiltration of the Class A disposal units would not adversely affect the other disposal units.

Recommendation. The criteria should be retained as is. Implementation at a shaft disposal facility is desirable and poses no technical problem.

Criterion 10 CFR 61.52 (a)(2) states: "Wastes designated as Class C pursuant to 10 CFR 61.55, must be disposed of so that the top of the waste is a minimum of 5 meters below the top surface of the cover or must be disposed of with intruder barriers that are designed to protect against an inadvertent intrusion for at least 500 years."

Discussion. Class C wastes represent the greatest potential radiological hazard of any waste acceptable for near-surface disposal. Consequently, these wastes should be isolated from the biosphere and the inadvertent intruder by a greater distance or barrier than other LLW. The requirement is valid and can be achieved by deeper disposal of Class C, by disposing of Class C only in the bottom of disposal units or with Class B or stabilized Class A wastes stacked above and around the sides of Class C wastes. Significant intruder barriers such as concrete or metal covers could also be used over the disposal units. High integrity shielding containers might also serve this purpose.

Recommendation. The criterion should be retained as is.

Criterion 10 CFR 61.52 (a)(3) states: "All wastes shall be disposed of in accordance with the requirements of paragraphs (a)(4) through (11) of this section."

Discussion. The referenced requirements are discussed individually below.

Recommendation. This umbrella criterion can be retained without impact for any disposal method.

Criterion 10 CFR 61.52 (a)(4) states: "Wastes must be emplaced in a manner that maintains the package integrity during emplacement, minimizes the void spaces between packages, and permits the void spaces to be filled."

Discussion. This requirement has several desirable goals. Rupture of packages during operations would result in higher risks of radiation exposure to workers, and could result in contamination of equipment, areas adjacent to the disposal unit, and even offsite contamination if contaminated equipment leaves the site.

Minimization of voids is the key to minimization of settlement. It also promotes efficient use of disposal space.

Recommendation. The criterion should be retained as is.

Criterion 10 CFR 61.52 (a)(5) states: "Void spaces between waste packages must be filled with earth or other solid material to reduce future subsidence within the fill."

Discussion. Minimization of subsidence will result in greatly reduced long-term maintenance problems, as discussed previously. Suitable materials that can be used for backfilling void spaces were also discussed previously. The goal of this criterion is sound and achievable if the right materials and care are used.

Recommendation. The criterion should be retained as is.

Criterion 10 CFR 61.52 (a)(6) states: "Waste must be placed and covered in a manner that limits the radiation dose rate at the surface of the cover to levels that at a minimum will permit the licensee to comply with all provisions of 10 CFR 20.105 of this chapter at the time the license is transferred pursuant to 10 CFR 61.30 of this part."

Discussion. This criterion has a valid and achievable goal and is directly applicable to shaft disposal. Additionally, during the "operational" period of each unit, radiation dosages must also be limited at the surface, and temporary covers or backfill should be placed over high activity wastes during the interim between placement and closure. It should be noted that the waste container and structural features of the disposal unit, e.g., the lining, would enhance shielding and reduce surface doses.

Placement of Class C wastes on the bottom of the disposal unit and Class B or stabilized Class A above would also reduce surface dose rates.

Relatively thick covers or shaft sealing plugs could also be used to meet the objective of this criterion.

Recommendation. The criterion should be retained as is.

Criterion 10 CFR 61.52 (a)(7) states: "The boundaries and locations of each disposal unit (e.g., trenches) must be accurately located and mapped by means of a land survey. Near-surface disposal units must be marked in such a way that the boundaries of each unit can be easily defined. Three permanent survey marker control points, referenced to United States Geological Survey (USGS) or National Geodetic Survey (NGS) survey control stations, must be established on the site to facilitate surveys. The USGS or NGS control stations must provide horizontal and vertical controls as checked against USGS or NGS record files."

Discussion. This requirement is necessary to ensure positive location of disposal units in case remedial action becomes necessary and to reduce the likelihood of inadvertent intrusion. These goals are desirable and technically achievable, using standard surveying methods.

Recommendation. The criterion should be retained as is.

Criterion 10 CFR 61.52 (a)(8) states: "A buffer zone of land must be maintained between any buried waste and the disposal site boundary and beneath the disposed waste. The buffer zone shall be of adequate dimensions to carry out environmental monitoring activities specified in 10 CFR 61.53(d) of this part and take mitigative measures if needed."

Discussion. This requirement was specified to ensure that adequate space and time would be available to detect and correct any performance deficiencies, i.e., radionuclide migration, before the deficiences manifest themselves at the site boundary. A fixed distance was not specified because of the variable relationship between radionuclide and ground-water travel times and site soil characteristics, primarily hydraulic conductivity and adsorption capacity. An additional consideration is to ensure that sufficient space exists between and around disposal units to carry out normal operations and closure activities. This is a practical requirement that can be easily implemented. The additional land requirements add only marginal costs; Rogers, Sutherland, and Adams (1982) have indicated that total land acquisition costs are only about 2 percent of total disposal costs for shallow land burial.

Recommendation. The criterion should be retained as is.

Criterion 10 CFR 61.52 (a)(9) states: "Closure and stabilization measures as set forth in the approved site closure plan must be carried out as each disposal unit (e.g., each trench) is filled and covered."

Discussion. As discussed by Pangburn and Pennifill (1982), the purpose of this requirement is primarily to minimize the number and extent of activities to be performed at the time of site closure. By closing and stabilizing disposal units as they are completed, the operator will be able to focus on final site closure and stabilization efforts at the end of site operations. Moreover, early closure and stabilization will help to minimize infiltration, lower dose rates to site personnel and protect waste package integrity. Early closure of filled disposal units also provides valuable experience from which to fine-tune final closure methods. Finally, if completed disposal units are not promptly closed and stabilized, the probability of achieving long-term isolation and avoidance of the need for continuing active maintenance could be compromised. Therefore, an applicant should provide, as part of the application, a closure and stabilization plan to be implemented upon completion of any given disposal unit. To assure closures within a reasonable time period, a construction sequencing plan with projected future waste quantities and categories should be submitted to indicate facility operation and closure time periods.

Disposal units that have been closed should be periodically inspected to ensure satisfactory performance. Such inspections should identify areas of erosion, cover cracking and settlement, ponding, and condition and extent of vegetation. Areas of lush vegetation should be checked to determine if these areas are wetter than adjacent areas.

Problems noted should be accompanied by plans for remedial actions. Subsequent inspections should note whether such remedial actions were undertaken and whether the noted problem has been corrected or still exists.

Procedures similar to this have been followed for decades by the Corps of Engineers in their periodic inspections and evaluations of locks and dams and other civil works.

Recommendation. The criterion should be retained as is.

Criterion 10 CFR 61.52 (a)(10) states: "Active waste disposal operations must not have an adverse effect on completed closure and stabilization measures."

Discussion. This requirement seeks to ensure that active operations do not result in damage to completed disposal units. Satisfaction of this requirement is achievable through planning of both normal operations and contingencies. Simple examples would include allowing enough room between disposal units for normal equipment movements without endangering adjacent units, temporary storage of excavated materials, and monitoring points.

Sufficient room should be provided between arrays of disposal units to allow for surface water management features and closure of completed units.

Recommendation. The criterion should be retained as is.

Criterion 10 CFR 61.52 (a)(11) states: "Only wastes containing or contaminated with radioactive materials shall be disposed of at the disposal site."

Discussion. This criterion is directly applicable to the shaft disposal alternative. However, it may not go far enough in stating what may not be disposed of, e.g., hazardous or toxic wastes that are slightly radioactive. This issue is considered within the criteria for waste characteristics, paragraph 61.56. The intent of 61.56 is to facilitate handling and to provide protection of worker health and safety. In addition, the potential for damage to the disposal unit resulting from chemically aggressive decomposition products of the wastes should be assessed.

Recommendation. The criterion should be retained as is.

3.3.3 Suggested Additional Technical Considerations

Except for the comments and suggestions made in the discussion of each existing criterion, only one additional technical consideration is thought to be necessary.

The additional consideration concerns the decommissioning and closure of monitoring stations.

Periodically during the operational period, specific monitoring points will either cease functioning or the data obtained from them will no longer be needed. Decisions will be required to either replace the monitoring point or decommission it.

If a subsurface monitoring point is decommissioned, i.e., a well or borehole, it should be sealed by injecting grout under pressure. An open well or boring represents a potential pathway for release of radionuclides that short-circuits the barriers provided in the closure of the disposal units. Care should be exercised to ensure that the well plugs do not shrink or crack or otherwise fail. They should be inspected and pressure tested to ensure they are properly sealed.

This consideration should receive increased emphasis for any disposal concept in which wastes would be disposed of below the water table.

3.4 Monitoring

3.4.1 Objectives of Monitoring

The overall objective of monitoring any low-level radioactive waste disposal facility is to provide reasonable assurance that the performance objectives are being met. Monitoring is considered to include the systematic collection, analysis, and interpretation of data related to the radiological, chemical, physical, and environmental properties of specific media in the vicinity of a LLW site during all phases of site life.

Monitoring should also include development of a plan of action to be implemented when one or more of the monitored parameter values exceeds a specified preestablished limit during or after the operations period (Lutton and others, 1983).

In addition to determining compliance with the performance objectives established in 10 CFR 61, the monitoring program should also:

a. Aid in site characterization.

b. Establish a statistical data base for background values of parameters of concern.

c. Provide a data base useful in the selection and verification of a site model.

d. Provide a method for determining when corrective actions are necessary, i.e., a plan of action to be implemented when the values of one or more parameters exceed a specified action level.

The monitoring program extends from the preoperational site investigation program through the operation period, and for some time after closure.

Lutton and others (1982a, 1982b, and 1983) in a series of three reports (NUREG/ CR-2700, NUREG/CR-3038, and NUREG/CR-3164) described the parameters which should be monitored, test methods and equipment required to measure these parameter values, and a comprehensive subsurface monitoring program that could achieve the intended objectives at LLW disposal sites.

Sedlett and others (1982) have also developed a handbook for environmental monitoring of LLW disposal sites.

Rogers, Sutherland, and Adam (1982) have developed a handbook for LLW disposal that discusses specific objectives and gives examples of monitoring techniques suitable for shallow land burial. Many of these recommendations would be equally applicable to a shaft disposal facility.

It is not the purpose of this report to make recommendations concerning a specific program for monitoring shaft disposal facilities. Such a program must be site specific and tuned to the design and plans for operation and closure of the facility.

The above references, NRC staff position papers, and the existing monitoring criteria, along with the recommendations in this report should provide adequate basis for development of specific monitoring programs.

It should be noted that, if the disposal facility is properly sited, designed, and operated, the major function of the monitoring program is to provide reassurance of satisfactory performance and safety of the facility.

3.4.2 Assessment of Existing Criteria

The existing criteria for assessment of environmental monitoring of land disposal of LLW are contained in paragraph 61.53 of 10 CFR 61 Subpart D. These four criteria are listed in subparagraphs 61.53(a)-(d) and are listed and discussed individually below.

Additional technical considerations are discussed at the end of this section.

Criterion 10 CFR 61.53 (a) states: "At the time a license application is submitted, the applicant shall have conducted a preoperational monitoring program to provide basic environmental data on the disposal site characteristics. The applicant shall obtain information about the ecology, meteorology, climate, hydrology, geology, geochemistry, and seismology of the disposal site. For those characteristics that are subject to seasonal variation, data must cover at least a twelve month period."

Discussion. This requirement is basic to the establishment of site suitability, design considerations, and operations and closure plans. While the specific information that is to be collected and its relative importance can be expected to vary, as well as the use to which it is put, the need for a systematic program is absolute.

For example, it can be reasonably concluded that ground-water aging is unnecessary at an arid site where disposal will take place far above the water table. However, this information is vital (for reasons discussed previously) for evaluation of any plan for disposal below the water table. It should be recognized that one year may be an insufficient length of time over which to document variations of some data of importance, such as water table fluctuations. Existing records should be used to supplement analyses based on such relatively short-term data collection periods.

Recommendation. This criterion should be retained as is.

Criterion 10 CFR 61.53 (b) states: "The licensee must have plans for taking corrective measures if migration of radionuclides would indicate that the performance objectives of Subpart C may not be met."

Discussion. This requirement is a valid one and suggests the need for further requirements that the licensee have on file plans for specific actions if detected concentrations or rates of radionuclide migration exceed preestablished limits.

The action plan should indicate methods and equipment to be used and the time table for mobilization. This requirement is keyed to the requirement for and size of the buffer zone, so that reaction and implementation of the planned action can be effected before radionuclides migrate beyond the site boundary.

Recommendation. The criterion should be retained as is.

Criterion 10 CFR 61.53 (c) states: "During the land disposal facility site construction and operation, the licensee shall maintain a monitoring program. Measurements and observations must be made and recorded to provide data to evaluate the potential health and environmental impacts during both the construction and the operation of the facility and to enable the evaluation of long-term effects and the need for mitigative measures. The monitoring system must be capable of providing early warning of releases of radionuclides from the disposal site before they leave the site boundary."

Discussion. The criterion is valid. It is recommended, however, that at the time of license application and review, specific reporting requirements be included. The reporting requirements should be keyed to the specific sample data and frequency of measurements of those data that would be required by analyses to demonstrate satisfactory performance.

In addition, a plan should be submitted for disposal of surface drainage water and ground water that has been sampled and tested, if such samples are found to contain significant radionuclide concentrations.

As discussed under the previous criterion, plans for mitigative measures should also be submitted for approval, prior to operation.

Recommendation. The criterion should be retained. However, it should be expanded to include the above requirements. Alternatively, these requirements should be incorporated in supplemental criteria.

Criterion 10 CFR 61.53 (d) states: "After the disposal site is closed, the licensee responsible for postoperational surveillance of the disposal site shall maintain a monitoring system based on the operating history and the closure and stabilization of the disposal site. The monitoring system must be capable of providing early warning of releases of radionuclides from the disposal site before they leave the site boundary."

Discussion. This requirement is valid. However, for the possible case of disposal in shafts below the water table, the benefits of leaving wells and boreholes open beyond the operating period should be weighed against the potential risks they pose as short circuits to the barriers to migration. It may be preferable to rely on demonstrated satisfactory performance, documented during the operation period. If it becomes necessary to obtain additional samples, new boreholes could be sunk for this purpose.

The above considerations do not invalidate the criterion, but point to the need for careful assessment of both the benefits and risks of specific monitoring points.

Recommendation. The criterion should be retained as is.

3.4.3 Suggested Additional Technical Considerations

Consideration should be given to adoption of a short-term, highly reliable monitoring program that would allow the disposal facility's performance to be established during the operational phase. The monitoring program could then be reduced as the facility's satisfactory performance is documented.

Other than the considerations discussed under the respective existing criteria, no additional technical considerations are thought to be necessary for a satisfactory environmental monitoring program.

4. CONCLUSIONS AND RECOMMENDATIONS

A significant amount of experience has been gained in the U. S. and abroad with storage of low-level radioactive waste in shafts. This experience base is of short duration (approximately 25 years) compared to the period of time required (100 to 500 years) for some low-level wastes to decay to levels that represent no significant health dangers.

Consequently, nearly all existing sites where shafts are used as the "engineered facility" have initially been called "storage facilities" by the owners. As part of this philosophy, practically all of these facilities have been designed and built with some provisions for retrieving the wastes, if necessary.

An active monitoring system has been included as an integral part of each facility to check on the facilities' performance and to provide an early warning of potential releases of radioactivity.

It is conceivable that some of these sites will eventually become disposal facilities as their proper performance is established through analysis of the monitoring data.

In the author's opinion, carefully conceived shaft disposal systems can satisfy all the performance objectives spelled out in 10 CFR 61 Subpart C. To meet these performance objectives, a systems approach is required for site characterization, design, construction, operations, closure, and monitoring. Favorable and unfavorable site characteristics must be identified and the impacts of unfavorable characteristics must be quantified. Design features should be targeted at taking advantage of the site's good qualities and improving the less satisfactory site characteristics. To achieve the design objectives, strict quality control and assurance should be emphasized during construction. Operations and closure must be carefully planned and implemented to complement the site's favorable characteristics and design features. Progressive closure of disposal units is recommended, to decrease risks of harmful exposures to workers and to build a data base on closure methods from which final closure plans can be enhanced.

If such a system is followed, a shaft disposal facility can be built using standard construction industry practices and commercially available equipment that would offer equal or greater capabilities for long-term waste isolation than existing shallow land burial practices.

Some of the practical considerations and features that could enhance the performance of a shaft disposal facility have been discussed in this report. Incorporating these features would, in almost all cases, result in higher first costs, e.g., use of a lining for disposal shafts. The benefits and costs of adopting any design feature must be assessed on a site-specific basis. The assessment should include analysis of avoided costs for extensive active maintenance.

The same analogy is valid for shallow land burial. Indeed, LLW disposal practices have evolved and improved over the years. In general, current practices for LLW disposal are safer now than they have ever been but at correspondingly higher initial costs.

LLW disposal in relatively shallow shafts is accurately defined as a near-surface disposal option. The methods and equipment for shaft disposal are not markedly different than trench disposal. (Exceptions were noted and discussed in previous sections of this report.)

Therefore, all of the existing criteria for evaluating site suitability, design, operations, closure, and monitoring of near-surface disposal facilities were judged to be applicable to shaft disposal.

The rationale behind the judgment of each individual criterion was stated in the preceding section of this report.

Additional technical considerations that should be addressed to allow complete evaluation of this disposal method were also discussed. Some of these considerations may best be addressed within the existing framework of minimum technical criteria and supporting regulatory guidance documents, e.g., NRC staff technical position papers and NUREG documents.

Some of these considerations may require development of specific supplemental criteria. Specific supplemental criteria wording has not been recommended in this report. Both the need for adoption of, and phrasing of any such criteria could best be determined by the NRC staff. It is hoped that the discussion of additional technical considerations contained in this report will facilitate this task.

Those issues recommended for consideration by the NRC are highlighted below.

To evaluate site suitability, consideration should be given to the occurrence, extent, and possible effects of dispersive soils, corrosive soils, expansive soils, geologic units capable of being dissolved (karst or cavern geology), liquefiable deposits, and areas of significant land subsidence.

Additional design considerations should focus on features that could enhance the site's natural characteristics and on plans for closure of individual disposal units.

The significant differences between disposal above and below the water table should be carefully analyzed for any proposed facility that promotes disposal below the water table. The differences in design requirements and functions will extend from the data to be obtained from the site characterization to the design and construction of components and features. Operations and closure methods and especially monitoring requirements would be quite different. For example, ground-water aging would provide important clues to site suitability and satisfactory performance for disposal below the water table.

Except for comments and suggestions made in the assessment of individual criteria, only one additional technical consideration is thought to be necessary for evaluation of operations and closure plans. That consideration is the replacement or decommissioning and closure of monitoring stations and devices. Periodically during and after the operating period, specific monitoring points will either cease functioning or the data obtained from them will no longer be required. Decisions will be required to either replace the monitoring point or decommission it.

Decommissioning should include closure of the monitoring device so that no short circuits develop in the natural protection system. For example, open wells or boreholes represent potential pathways of escape for radionuclides. For disposal below the water table, these holes should be plugged after their usefulness as monitoring points end.

Considerations that should receive emphasis within the context of existing criteria include: the need for proper selection, placement, and compaction of backfill and cover materials; the need for prompt closure of filled disposal units to build an experience base and fine-tune final closure plans. The closure plan should recognize and seek to minimize interferences likely to arise between ongoing disposal operations and closure of individual disposal units; the need for an integrated detailed plan for inspection, periodic maintenance, and remedial action of identified problems such as the periodic inspection and evaluation system followed by the Corps of Engineers; and the need to specify what may not be disposed of at a shaft disposal facility for LLW.

Additional technical considerations that may be considered within the framework of existing minimum technical requirements for monitoring programs include: an assessment of the need for and details of a plan of action for remedial measures; the need for encouraging a systematic program for data collection (type of data, locations and frequency) and analysis that allows trends to be discerned and their impacts evaluated. Remedial actions should be keyed to observation of specified concentrations of radionuclides. Specific reporting requirements should be established as a check on the system's performance.

An additional technical consideration that may require attention is the need for adoption of a short-term highly reliable monitoring program that would allow the disposal site's performance to be established during the operations phase. The monitoring program could then be reduced as satisfactory performance is verified.

Unresolved Issues and Recommended Research Areas

During the course of this investigation several issues or questions have been raised for which there were no ready answers.

In general, these questions have been concerned with long-term performance and reliability. All experience gained to date that is directly applicable to LLW disposal is short-term, 40 years or less. The goal for satisfactory LLW disposal is to isolate the wastes from man and the environment until the wastes have decayed to levels that present no significant health risks. The time period required to achieve this goal is dependent on waste characteristics, i.e., the half lives and concentrations of the radioactive isotopes that make up the waste. Cobalt-60 (half-life 5.3 yr), Iodine-131 (half-life 8 days), tritium (half-life 12.3 yr), Cesium-137 (half-life 30.2 hr), Strontium-90 (half-life 28.8 yr), Cesium-134 (half-life 2.1 yr), and Carbon-14 (half-life 5730 yr) dominate the make-up of low-level wastes.

With the exception of Carbon-14, the concentrations of these isotopes would be less than one-tenth of 1 percent (0.1 percent) of their initial concentrations after 300 years. The remaining concentrations of some of these isotopes are practically zero, e.g., tritium and Iodine-131.

These facts, together with limits prescribed by the NRC on activity levels per unit volume have led to adoption of a 100 year period for institutional control and a 500 year period for intruder barriers for Class C wastes as a goal for long-term isolation of LLW.

The 500 yr effective life of the intruder barrier presents a technical challenge. With few exceptions, no long-term data are available on the durability and performance of materials used for intruder barriers.

This problem has been recognized and some research is being conducted. For example, the Corps of Engineers has performed accelerated concrete weathering tests for years (for different reasons). Appendix A of this report describes factors that impair long-term durability of concrete and design and construction practices that may be used to minimize adverse impacts. Long-term performance of bentonite and bentonite mixtures is being studied by the AECL in Canada and researchers in Sweden. The results of all pertinent research should be organized and brought into focus and supplemented as necessary so that designers may choose materials and methods that are most likely to meet long-term performance objectives.

For the shaft disposal alternative, the research should focus on material selection and design and construction methods for shaft linings, backfill, shaft seals, caps and covers. The effects of moisture and corrosive salts in soils would be important considerations in this regard.

Long-term performance of drainage layers is also important to the overall objective of waste isolation. Proper design practice, construction methods, and maintenance requirements should be documented and organized. Alternative designs for drainage and cover systems should be tested and evaluated.

A need exists for development of conceptual designs of monitoring systems that could, with a high degree of reliability, establish the satisfactory performance of a disposal facility. Again, some research has been aimed at the monitoring problem (Lutton and others, 1982a, 1982b, and 1983; Sedlett and others, 1982). However, more information is needed on the durability and reliability of specific instruments and test procedures to make the best use of previous research and to develop relatively inexpensive but reliable monitoring systems.

Improvement of waste packages is receiving some emphasis and this research should be encouraged. Improved waste packages that resist corrosion and degradation can only help in the overall long-term facility performance.

Recent research aimed at development of engineered sorbent barriers to radionuclide migration such as reported by Freeman, Hartley, and Buelt (1984) should be supported and encouraged.

The potential advantages of waste segregation prior to disposal in engineered facilities should also be investigated. Although outside the scope of this study, it could be implied that LLW disposal in engineered facilities will result in a higher degree of waste isolation at a corresponding higher cost per unit volume. Thus there may be a definite economic advantage to segregation and disposal of the relatively low volumes of higher activity wastes in engineered facilities.

The issue of below water table disposal should be thoroughly investigated. Previous research by Cherry, Gillham, and others should form the basis for additional work. Regions should be identified where suitable geological and hydrological conditions exist for this method to work. Conditions that could result in unsatisfactory performance, e.g., fractured rock, exploitable natural resources, should be identified and avoided. Engineered barriers and improved waste packages could play important roles in the option of disposal below the water table.

REFERENCES

N. V. Beamer and others, "Studies of Reactor Waste Conditioning and Disposal at CRNL," Atomic Energy of Canada Limited Report AECL-7551, Chalk River, Ontario, Canada, Sep 1982. Available for purchase from Scientific Document Distribution Office, Atomic Energy of Canada Limited, Chalk River, Ontario, Canada KOJ 1J0.

R. D. Bennett, W. O. Miller, J. B. Warriner, P. G. Malone, and C. C. McAneny "Alternative Methods for Disposal of Low-Level Radioactive Wastes; Task 1: Description of Methods ad Assessment of Criteria" Report No. NUREG/CR-3774, vol. 1, April 1984; prepared for US Nuclear Regulatory Commission, Division of Waste Management, Washington, DC, 20555. Prepared by US Army Engineer Waterways Experiment Station, PO Box 631, Vicksburg, MS 39180.

L. Borgesson, "Buffer Mass Test-Predictions of the Behavior of the Bentonite-Based Buffer Materials," Internal Stripa Project Report 82-08, August 1982, prepared for Swedish Nuclear Fuel Supply Co., by University of Lulea, Sweden.

D. H. Card and others, Ford, Bacon and Davis Utah, Inc., "Criteria for Greater Confinement of Radioactive Wastes at Arid Western Sites," USDOE Report NVO-234, May 1981. Available for purchase from National Technical Information Service, Springfield, VA 22161.

D. H. Charlesworth and T. J. Carter, "Low- and Intermediate-Level Radioactive Waste Management in Canada," Atomic Energy of Canada Limited, Report AECL-7629, Chalk River, Ontario, Canada (May 1982). Available for purchase from Scientific Document Distribution Office, Atomic Energy of Canada Limited, Chalk River, Ontario, Canada KOJ 1J0.

J. A. Cherry, G. E. Grisak, and R. E. Jackson, "Hydrogeological Factors in Shallow Subsurface Radioactive Waste Management in Canada," Proceedings, International Conference on Land for Waste Management, Ottawa, Ontario, National Research Council, Canada, 1974, pp 131-146.

J. A. Cherry and R. W. Gillham, "A Concept for Long-Term Isolation of Solid Radioactive Waste in Fine-Grained Deposits," Proceedings, Symposium on Management of Low-Level Radioactive Waste, U. S. Geological Survey and U. S. Environmental Protection Agency, Atlanta, Georgia, May 1977, M. W. Carter, editor, Pergamon Press, NY, pp 1021-1040.

J. J. Cohen, P. T. Dickman, and others, Science Applications, Inc., and Reynolds Electrical and Engineering Co. (resp.), "Comparative Assessment of Disposal of TRU Waste in a Greater Confinement Disposal Facility," USDOE Report DOE/NV/00410-68, Nov 1982. Available for purchase from National Technical Information Service, Springfield, VA 22161.

J. R. Cook, "Final Report: Greater Confinement Disposal Technology at the Savannah River Plant," 1984, prepared for U. S. Department of Energy by E. I. Dupont de Nemours and Co., Inc., Savannah River Laboratory, Aiken, SC 29808.

P. T. Dickman and J. R. Boland, "Greater Confinement Disposal Test, Fiscal Year 1983 Progress," pp 316-323 in Proceedings of the Fifth Annual Participants' Information Meeting, DOE Low-Level Waste ManagementProgram, DOE Conference Proceedings CONF-8308106, Dec 1983. Available for purchase from National Technical Information Service, Springfield, VA 22161.

D. F. Dixon, "Strategy for the Disposal of Low- and Intermediate-Level Radwastes in Canada," Atomic Energy of Canada Limited Report AECL-7439, Chalk River, Ontario, Canada, June 1981. Available for purchase from Scientific Document Distribution Office, Atomic Energy of Canada, Limited, Chalk River, Ontario, Canada KOJ 1J0.

M. A. Feraday, "Canadian Experience with the Storage and Disposal of Low- and Intermediate-Level Wastes," Proceedings of the Symposium on Low-Level Waste Disposal, USNRC Conference Proceedings NUREG/CP-0028, Vol 3, pp 411-429, Sep 1982. Available for purchase from the National Technical Information Service, Springfield, VA 22161.

M. A. Feraday, "A Prospectus for the Development of Shallow Land Burial Disposal Concepts for the CRNL Site," Chalk River Nuclear Laboratories Technical Record TR-307, Chalk River, Ontario, Canada, June 1983. Available from Scientific Document Distribution Office, Atomic Energy of Canada Limited, Chalk River, Ontario, Canada KOJ 1J0.

P. Forsythe, "Experience in Identification and Treatment of Dispersive Clays in Mississippi Dams," Dispersive Clays, Related Piping, and Erosion in Geotechnical Projects, American Society for Testing and Materials, Special Technical Publication No. 623, May 1977, pp 135-155.

H. D. Freeman, J. N. Hartley, and J. L. Buelt, "Engineered Sorbent Barriers for Low Level Waste," Pacific Northwest Laboratory, Richland, WA, Sep 84.

P. Fritz, J. F. Barker, and J. E. Gale, "Geochemistry and Isotope Hydrology of Ground Waters in the Stripa Granite: Results and Preliminary Interpretation," Technical Information Report No. 12 (LBL-8285, SAC-12, UC-70), April 1979, Swedish-American Cooperative Program on Radioactive Waste Storage in Mined Caverns in Crystalline Rock, A Joint Project of Swedish Nuclear Fuel Supply Co. and Lawrence Berkeley Laboratory, Univ. of California. Report available from National Technical Information Service, US Department of Commerce, 5285 Port Royal Road, Springfield, VA 22161.

R. W. Gillham and J. A. Cherry, "Predictability of Solute Transport in Diffusion Controlled Hydrogeology Regimes," Proceedings, Symposium on Low-Level Waste Disposal, Facility Design, Construction, and Operating Practices, NUREG/CP-0028, Conf 820911, Vol. 3, pp 379-410, March 1983.

K. M. Harmon and others, "International Nuclear Fuel Cycle Fact Book," Pacific Northwest Laboratory Report PNL-3954 Rev. 3, issued Nov. 1980, latest revision March 1984. Available from Nuclear Waste Technology Program Office, Pacific Northwest Laboratory, PO Box 999, Richland, WA 99352.

R. L. Hooker, "Greater Confinement Disposal," pp 781-794 in Proceedings of the Fourth Annual Participants Information Meeting, DOE Low-Level Waste Management Program, October 1982, ORNL Conference Proceedings ORNL/NFW-82118, Available for purchase from National Technical Information Service, Springfield, VA 22161.

D. E. Jones and W. G. Holtz, "Expansive Soils--The Hidden Disaster," Civil Engineering, American Society of Civil Engineers, New York, Aug 1973, p. 49-51.

D. R. Lamb and S. J. Hanna, "Summary of Proceedings of Workshop on Expansive Clays and Shales in Highway Design and Construction," FHWA-RD-73-72, Federal Highway Administration, Washington, D.C., May 1973.

R. J. Lutton, W. E. Strohm, Jr., and A. B. Strong, "Subsurface Monitoring Programs at Sites for Disposal of Low-Level Radioactive Waste," NUREG/CR-3164, April 1983, prepared for US Nuclear Regulatory Commission by Geotechnical Laboratory, US Army Engineer Waterways Experiment Station, PO Box 631, Vicksburg, MS 39180.

R. J. Lutton and others, "Tests for Evaluating Sites for Disposal of Low-Level Radioactive Waste," NUREG/CR-3038, December 1982, prepared for US Nuclear Regulatory Commission by Geotechnical Laboratory, US Army Engineer Waterways Experiment Station, PO Box 631, Vicksburg, MS 39180.

R. J. Lutton and others, "Parameters for Characterizing Sites for Disposal of Low-Level Radioactive Waste," NUREG/CR-2700, May 1982, Prepared for US Nuclear Regulatory Commission by Geotechnical Laboratory, US Army Engineer Waterways Experiment Station, PO Box 631, Vicksburg, MS 39180.

P. J. MacBeth and others, Ford, Bacon, and Davis Utah, Inc., "Screening of Alternative Methods for the Disposal of Low-Level Radioactive Wastes," USNRC Report NUREG/CR-308, UC 209-02, October 1978, Available for purchase from National Technical Information Service, Springfield, VA 22161.

P. J. MacBeth and others, Ford, Bacon, and Davis Utah, Inc., "Evaluation of Alternative Methods for the Disposal of Low-Level Radioactive Wastes," USNRC Report NUREG/CR-0680, FBDU-209-03, July 1979, Available for purchase from National Technical Information Service, Springfield, VA 22161.

P. A. Miskimin and S. C. Cosell, "The Comprehensive Waste Management System and A Unique Approach to Onsite LLW Storage," Proceedings, Waste Management '84, Waste Isolation in the U. S., Technical Programs and Public Education, Vol 2, Low-Level Waste, Volume Reduction Methodologies and Economies, March 1984, Roy Post, Ed., pp 511-518.

J. A. Morrison, "AECL Experience in Managing Radioactive Wastes from Canadian Nuclear Reactors," Atomic Energy of Canada Limited Report AECL-4707, Chalk River, Ontario, Canada (March 1974), Available for purchase from Scientific Document Distribution Office, Atomic Energy of Canada Limited, Chalk River, Ontario, Canada KOJ 1J0.

M. Muroi and others, "Ion-Migration Through Bentonite-Zeolite and Bentonite-Quartz Sand Mixture," Proceedings Waste Management '84, Waste Isolation in the U. S., Technical Programs and Public Education, Vol 2-Low-Level Waste, Volume Reduction Methodologies and Economics, Roy G. Post, ed., pp 495-502.

National Research Council, Panel on Land Burial, Committee on Radioactive Waste Management, Commission on Natural Resources, "The Shallow Land Burial of Low-Level Radioactively Contaminated Solid Waste," National Academy of Sciences Report, 1976, Available from Printing and Publishing Office, National Academy of Sciences, 2101 Constitution Avenue, N.W., Washington, DC 20418.

G. C. Pangburn and R. A. Pennifill, "Technical Position on Near-Surface Disposal Facility Design and Operation," November 1982, US Nuclear Regulatory Commission, Division of Waste Management, Low-Level Waste Licensing Branch.

D. M. Patrick and D. R. Snethen, "An Occurrence and Distribution Survey of Expansive Materials in the United States by Physiographic Areas," FHWA-RD-76-82, Federal Highway Administration, Washington, D.C., Jan 1976.

Edward B. Perry, "Susceptibility of Dispersive Clay at Grenada Dam, Mississippi, to Piping and Rainfall Erosion," Technical Report GL-79-14, September 1979, U. S. Army Engineer Waterways Experiment Station, Geotechnical Laboratory, P. O. Box 631, Vicksburg, MS 39180.

J. T. Phillips, "Case Histories of Repairs and Designs for Dams Built with Dispersive Clays," Dispersive Clays, Related Piping, and Erosion in Geotechnical Projects, ASTM STP 623, J. L. Sherard and R. S. Decker, Eds., American Society for Testing and Materials, 1977, pp 330-340.

W. D. Purtymun, "Underground Movement of Tritium from Solid Waste Storage Shafts," Los Alamos Scientific Laboratory Report No. LA-5286-MS, 1973, Available from National Technical Information Service, Springfield, VA 22161.

V. C. Rogers, A. A. Sutherland, and J. A. Adam, "A Handbook for Low-Level Radioactive Waste Disposal Facilities," prepared for Electric Power Research Institute, 3412 Hillview Avenue, Palo Alto, CA 94304, by Rogers and Associates Engineering Corporation, P. O. Box 33, Salt Lake City, UT 84110 (Interim Report), September 1982.

C. J. Rosewell, "Identification of Susceptible Soils and Control of Tunnelling Failure in Small Earth Dams," Dispersive Clays, Related Piping, and Erosion in Geotechnical Projects, ASTM STP 623, J. L. Sherard and R. S. Decker, Eds., American Society for Testing and Materials, 1977, pp 362-369.

R. C. Schmitt and others, "High Integrity Containers: Demonstrated Disposal Alternative to Solidification of Radioactive Waste," March 1984, Proceedings Waste Management '84, Waste Isolation in the US, Technical Programs and Public Education, Volume 2 - Low-Level Waste, Volume Reduction Methodologies and Economics, Roy G. Post, ed., pp 537-544.

Jacob Sedlett and others, "Generic Handbook, Environmental Monitoring for Low-Level Waste Disposal Sites," August 1982, Prepared for US Department of Energy, by Argonne National Laboratory, Argonne, Illinois.

D. Siefken, G. Pangburn, R. Pennifill, and R. J. Starmer, "Site Suitability, Selection and Characterization," Branch Technical Position Paper, Low-Level Waste Licensing Branch, Division of Waste Management, Office of Nuclear Material Safety and Safeguards, US Nuclear Regulatory Commission, Washington, D.C. 20555, April 1982.

J. L. Sherard and others, "Pinhole Test for Identifying Dispersive Soils," Journal of the Geotechnical Engineering Division, American Society of Civil Engineers, Vol 102, No. GT1, January 1976, pp 69-85.

D. R. Snethen, and others, "A Review of Engineering Experience with Expansive Soils in Highway Subgrades," FHWA-RD-75-48, Federal Highway Adiminstration, Washington, D.C., Jun 1975.

D. R. Snethen, L. D. Johnson, and D. M. Patrick, "An Investigation of the Natural Microscale Mechanisms that Cause Volume Changes in Expansive Clays," FHWA-RD-77-75, Federal Highway Administration, Washington, D.C., Jan 1977.

D. R. Snethen, L. D. Johnson, D. M. Patrick, "An Evaluation of Expedient Methodology for Identification of Potentially Expansive Soils," FHWA-RD-77-94, Federal Highway Administration, Washington, D.C., Jun 1977.

D. R. Snethen, "An Evaluation of Methodology for Prediction and Minimization of Detrimental Volume Change of Expansive Soils in Highway Subgrades," Vol I, FHWA-RD-79-49, Federal Highway Administration, Washington, D.C., Mar 1979.

D. R. Snethen, "An Evaluation of Methodology for Prediction and Minimization of Detrimental Volume Change of Expansive Soils in Highway Subgrades," Vol II, Appendices, FHWA-RD-79-50, Federal Highway Administration, Washington, D.C., Mar 1979.

Oscar A. Towler, J. R. Cook, and D. L. Peterson, "Greater Confinement Disposal Program at the Savannah River Plant," Proceedings, 5th Annual Participants Information Meeting, DOE Low-Level Waste Managment Program, US Department of Energy National Low-Level Radioactive Waste Management Program, December 1983, pp 308-315.

P. G. Tucker, "Trench Design and Construction Techniques for Low-Level Radioactive Waste Disposal," NUREG/CR 3144, February 1983, Prepared for US Nuclear Regulatory Commission by Geotechnical Laboratory, US Army Engineer Waterways Experiment Station, PO Box 631, Vicksburg, MS 39180.

GLOSSARY

ACTIVE MAINTENANCE: Any significant remedial activity needed during the period of institutional control to maintain a reasonable assurance that the performance objectives in 10 CFR 61.41 and 61.42 are met. Such active maintenance includes ongoing activities such as the pumping and treatment of water from a disposal unit or one-time measures such as replacement of a disposal unit cover. Active maintenance does not include custodial activities such as repair of fencing, repair or replacement of monitoring equipment, revegetation, minor additions to soil cover, minor repair of disposal unit covers, and general disposal site upkeep such as mowing grass.

ACTIVITY: A measure of the rate at which a material is emitting nuclear radiations; usually given in terms of the number of nuclear disintegrations occurring in a given quantity of material over a unit of time; the standard unit of activity is the curie (Ci), which is equal to 3.7×10^{10} disintegrations per second.

AGREEMENT STATES: Any States with which the Commission or the AEC has entered into an effective agreement under subsection 274b of the Atomic Energy Act of 1954. A Nonagreement State is any other State. (10 CFR 150.3)

AQUICLUDE: A formation which, although porous and capable of absorbing water, does not transmit it at rates sufficient to furnish an appreciable supply for a well or spring. (ASTM STP 746)

AQUIFER: Geologic stratum or set of beds with relatively high transmissivity and carrying ground water in quantities to make exploitation for consumption economically feasible.

AUGERED HOLES: Cylindrical, near-vertical holes or shafts excavated by spiral augers or other methods.

BACKGROUND RADIATION: Radiation in the environment from naturally occurring radioactive elements, cosmic radiation, and fallout from man's activities such as nuclear weapons testing.

BUFFER ZONE: A portion of the disposal site that is controlled by the licensee and that lies under the disposal units and between the disposal units and the boundary of the site.

CURIE (Ci): A unit of radioactivity defined as the amount of a radioactive material that has an activity of 3.7×10^{10} disintegrations per second (d/s); millicurie (mCi) = 10^{-3} curie; microcurie (Ci) = 10^{-6} curie; nanocurie (nCi) = 10^{-9} curie; picocurie (pCi) = 10^{-12} curie; femtocurie (fCi) = 10^{-15} curie.

DECONTAMINATION: The selective removal of radioactive material from a surface or from within another material.

DISPOSAL SITE: That portion of a land disposal facility which is used for disposal of waste. It consists of disposal units and a buffer zone.

DISPOSAL UNIT: A discrete portion of the disposal site into which waste is placed for disposal. For current near-surface disposal the unit is usually a trench.

ENGINEERED BARRIER: A man-made structure or device that is intended to improve a land disposal facility's ability to meet the performance objectives in 10 CFR Part 61, Subpart C.

ENGINEERED DISPOSAL: As used in this report, the disposal of radioactive wastes, usually in suitable sealed containers, in any of a variety of structures especially designed to protect them from water and weather and to prevent leakage to the biosphere by accident or sabotage.

ENVIRONMENTAL SURVEILLANCE: Monitoring of the impact on the surrounding region of the discharges from industrial operations, forest fires, storm runoff, or other natural or man-induced events.

EXPOSURE: A measure of the ionization produced in air by X or gamma radiation. It is the quotient of (1) the sum of the electrical charges on all ions of one sign produced in air when all electrons liberated by photons in a volume element of air are completely stopped in air, divided by (2) the mass of the air in the volume element. The special unit of exposure is the Roentgen. (Radiological Health Handbook, U. S. Dept. of HEW). Acute exposure generally refers to a high level of exposure of short duration; chronic exposure is lower-level exposure of long duration.

GROUND WATER: Water that exists or flows below the ground surface (within the zone of saturation).

GROUT: Fluid or semifluid material, often containing Portland cement, which may be pumped or poured into earth strata and by setting up into a solid state, provides mechanical stabilization or water flow control.

HALF-LIFE: The time in which half the atoms of a particular radioactive substance disintegrate to another nuclear form. Measured half-lives vary from millionths of a second to billons of years. After a period of time equal to 10 half-lives, the radioactivity of a radionuclide has decreased to 0.1 percent of its original level.

HAZARDOUS WASTE: Those wastes designated as hazardous by Environmental Protection Agency regulations in 40 CFR Part 261.

HYDROGEOLOGY: The study of ground water, with particular emphasis on its chemistry, mode of migration, and relation to the geologic environment. (Davis and De Wiest, 1966).

HYDROGEOLOGIC UNIT: Any soil or rock unit or zone which by virtue of its porosity or permeability, or lack thereof, has a distinct influence on the storage or movement of ground water.

IN SITU: In the natural or original position; used to refer to inplace experiments at a storage or disposal site.

INADVERTENT INTRUDER: A person who might occupy a disposal site after closure and engage in normal activities, such as agriculture, dwelling construction, or other pursuits, in which the person might be unknowingly exposed to radiation from the waste.

INTRUDER BARRIER: A sufficient containment of the waste that inhibits human contact with waste and helps to ensure that radiation exposures to an inadvertent intruder will meet the performance objectives set forth in 10 CFR 61; or engineered structures that provide equivalent protection to the inadvertent intruder.

ION: Atomic particle, atom, or chemical radical bearing an electrical charge, either negative or positive.

ION EXCHANGE: A reversible interchange that takes place between ions of like charge, usually between ions present on an insoluble solid and ions in a solution surrounding the solid. An important process in both fundamental and industrial chemistry.

ION-EXCHANGE RESIN: An insoluble polymerized electrolyte that contains either acidic groups for exchanging cations or basic groups for exchanging anions. It contains large, high-molecular-weight ions of one charge and small, simple ions of the opposite charge. The small ions undergo exchange with ions in solution.

IONIZING RADIATION: Any electromagnetic or particulate radiation capable of producing ions, directly or indirectly, in its passage through matter.

ISOTOPES: Nuclides having the same number of protons in their nuclei, and hence the same atomic number, but differing in the number of neutrons, and therefore in the mass number. Identical chemical properties exist between isotopes of a particular element.

KARST: Surface or subsurface rock mass conditions characterized by solution-formed caverns, cavities, open joints, pinnacles, and depressions of a highly irregular form. Almost exclusively applied to carbonate lithologies, e.g., limestone.

LAND DISPOSAL FACILITY: Land, buildings, and equipment intended to be used for the disposal of radioactive wastes into the subsurface of the land. A geologic repository as defined in 10 CFR 60 is not considered a land disposal facility. (10 CFR 61.2)

LEACHING: The process of extracting a soluble component from a solid by the percolation of a solvent (e.g., water) through the solid.

LIQUEFIABLE: Susceptible to near-total loss of shear strength and bearing capacity duing seismic disturbances; used with reference to soils.

LITHOLOGY: The character of a rock formation or of the rock found in a geological area or stratum expressed in terms of its structure, mineral composition, color, and texture.

LOW-LEVEL RADIOACTIVE WASTE (LLW): Radioactive waste not classified as high-level radioactive waste, transuranic waste, spent nuclear fuel, or by-product material as defined in section 11e. (2) of the Atomic Energy Act of 1954. (P.L. 96-573) Radioactive wastes containing source, special nuclear, or by-product material that are acceptable for disposal in a land disposal facility (10 CFR 61.2) For explanation of Class A, Class B, and Class C LLW, see 10 CFR 61.55 and 61.56.

NEAR-SURFACE DISPOSAL FACILITY: A land disposal facility in which radioactive waste is disposed of in or within the upper 30 meters of the earth's surface.

PERMEABILITY: The capacity of a porous medium to conduct liquids or gases.

PIEZOMETER: An instrument for measuring pressure head in ground water. In an unconfined aquifer with a free water table a piezometer is frequently an open-bottomed monitor well extending below that water table.

PSYCHROMETER: Device used for measuring the amount of water vapor in air; e.g., a hygrometer.

PYROPHORIC: Igniting spontaneously. A pyrophoric liquid is any liquid that ignites spontaneously in dry or moist air at or below 130°F (54.5°C). A pyrophoric solid is any solid material, other than one classed as an explosive, which under normal conditions is liable to cause fires through friction, retained heat from manufacturing or processing, or which can be ignited readily and when ignited burns so vigorously and persistently as to create a serious transportation, handling, or disposal hazard. Included are spontaneously combustible and water-reactive materials.

RAD: The unit of absorbed dose equal to 100 ergs per gram or 0.01 joule per kilogram.

RADIOACTIVITY: The property of certain nuclides of spontaneously emitting particles or gamma radiation, or of emitting X radiation following orbital electron capture, or of undergoing spontaneous fission. (Radiological Health Handbook, U. S. Dept. of HEW)

REM: A special unit of dose equivalent. The dose equivalent in rems is numerically equal to the absorbed dose in rads multiplied by the quality factor, the distribution factor, and any other necessary modifying factors. (Radiological Health Handbook, U. S. Dept. of HEW) The dosage of any ionizing radiation that will cause the same amount of biological injury to human tissue as one roentgen of X-ray or gamma-ray dosage. (Webster's Third New International Dictionary) (1 millirem = 0.001 REM)

REPOSITORY: A term generally applied to a facility for the disposal of radioactive wastes, particularly high-level waste and spent fuel.

ROENTGEN: The special unit of exposure. One roentgen equals 2.58×10^{-4} coulomb per kilogram of air. (Radiological Health Handbook, U. S. Dept. of HEW) The international unit of X radiation or gamma radiation that is the amount of radiation producing, under ideal conditions in one cubic centimeter of air at 0°C and 760 mm Hg pressure, ionization of either sign equal to one electrostatic unit of charge. (Webster's Third New International Dictionary)

SEISMIC: Of, pertaining to, of the nature of, subject to, or caused by an earthquake.

SITE CLOSURE AND STABILIZATION: Those actions that are taken upon completion of operations that prepare the disposal site for custodial care and that assure that the disposal site will remain stable and will not need ongoing active maintenance.

SUBSIDENCE: Sinking or depression of the ground surface; generally due to loss of subsurface support.

SURVEILLANCE: Observation of the disposal site for purposes of visual detection of need for maintenance, custodial care, evidence of intrusion, and compliance with other license and regulatory requirements.

TECTONIC: Of or relating to the deformation of the earth's crust, the forces involved in or producing such deformation, and the resulting rock structures and external forms.

TILEHOLE: A form of augered hole which is lined with ceramic, concrete, or metal fabrications and may be used for retrievable radioactive waste storage.

TRANSMISSIVITY: A property of an aquifer; the rate at which water of the prevailing kinematic viscosity is transmitted through a unit width of the aquifer under a unit hydraulic gradient.

UNSATURATED ZONE: The zone of soil or rock between the ground surface and the water table; also termed the vadose zone.

VAULT: An artificial enclosed space covered by an overhead structure; especially a passage or room used for storage or safekeeping.

VULCANISM: The processes by which magma (molten rock material within the earth) and its associated gases rise into the earth's crust and are extruded onto the earth's surface and into the atmosphere.

WATER TABLE: The surface within an unconfined aquifer between the zone of saturation and the zone of aeration; that surface of a body of unconfined ground water at which the pressure is equal to atmospheric pressure.

APPENDIX A

Long Term Performance and Durability of Portland Cement Concrete as the Building Material for Engineered Facilities

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1. Introduction

The disposal of low-level radioactive waste in engineered facilities requires an in-depth evaluation of the construction materials used to attempt the prediction of the service life of structures used for this disposal. This section of the report addresses the parameters to be considered in the use of reinforced portland-cement concrete as the building material for disposal vault or other engineered facilities.

Predicting behavior and durability of materials and structures for long periods of time, such as 500 years, has, as its foundation, extrapolation of short-term data, which in many cases may lack a proper rationale. The ancient Roman engineers and builders produced constructions that we can examine today but passed on very little written narrative of how they designed and constructed their projects (Malinowski, 1979). Present-day efforts to reconstruct, by deduction, the formulation of concrete mixtures, the identification of the exact materials, and a definite statement as to construction methodology have met with only slight success (Malinowski, 1979 and Roy and Langton, 1983). However, these studies permit better understanding of the aging process that may be expected for certain materials.

Predicting the long-term stability and performance of materials such as cements, mortars, and concrete may be approached in two ways: (1) examination of the physical performance of old structures and (2) interpretation of the chemical activity of the observed durability of old cementing materials.

Long-term performance is an approximate synonym of durability, and the factors which impair such durability will determine its long-term performance.

Generally, concrete durability depends on its porosity, permeability, absorptivity, capillarity, response to imposed stresses, and bond of the components.

2. Factors that Impair the Integrity of Concrete

The structural integrity of a reinforced portland-cement concrete structure is a function of the quality and durability of the structure in response to the applied loads and stresses and of the durability and quality of the concrete contained in the structure. Durability of a structure has been defined (ASTM, 1977) as "the safe performance of a structure or a portion of a structure for the designed life expectancy." Durability of portland cement concrete has been defined (ACI, 1977) as "its ability to resist weathering action, chemical attack, abrasion, or any other process of deterioration." It is essential to recognize the main types of concrete deterioration and then address measures and techniques that can be employed to protect against these attacks.

American Concrete Institute (ACI) Committee 201 (ACI, 1977) has listed five important causes of concrete deterioration as: (1) freezing and thawing, (2) aggressive chemical exposure, (3) abrasion, (4) corrosion of steel and other metals embedded in concrete, and (5) chemical reactions of aggregates. The following paragraphs define and discuss these causes.

2.1 Freezing and Thawing

Freezing and thawing damage is the phenomenon that occurs when critically saturated concrete is subjected to freezing and thawing. Hardened cement paste and aggregate have very different behavior responses to freezing and thawing and therefore should be considered separately.

2.1.1 Freezing and thawing of cement paste. The porosity of cement paste, in fairly dense and well consolidated concrete, is between 30 percent and 50 percent. This pore structure becomes reservoirs for water which can freeze and cause disruptive and damaging action. The research done by Powers (1945, 1954, 1955), Helmuth (1960), Collins (1944), and Litvan (1974) produced what is generally accepted as the mechanisms taking place during freezing, though each researcher's findings differ somewhat in detail. It is now believed by many researchers that osmotic pressure of the freezing water in the pores and connecting capillaries causes most of the frost damage in cement paste (ASTM, 1977). The pressures generated by this mechanism cause the paste to fail, which in turn, causes the concrete mass to fail.

Generally, it is agreed (and has been demonstrated time and again) that air entrainment of cement paste can produce a paste that will not be affected by freezing and thawing provided sufficient hydration of cement has taken place before the paste is allowed to freeze while critically saturated. Air entrainment produces a pore distribution system, with appropriate distances between pores, which will accommodate ice movement and pressures.

2.1.2 Freezing and thawing of aggregate particles. As just stated, air entrainment can prevent damage in cement paste, but the freezing action in aggregate particles must also be considered so as to produce a concrete that will be free of damage.

The basic mechanism is called "the hydraulic pressure theory (ASTM, 1977)." Powers (1945) found that the pores of rocks, which are often larger than paste pores, if water filled, expel water during freezing and thereby produce a hydraulic pressure which can cause failure.

In addition, Verbeck and Landgren (1960) found that in coarse aggregate from any given natural rock, there is a critical size below which, if unconfined by cement paste, the material can be frozen without damage.

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The overall effect on a concrete composed of sound aggregate and paste of appropriate maturity which has an appropriate air-entrained void system characterized by a spacing factor (maximum distance from any point in the paste to the periphery of a nearby air void) of less than 0.008 in. is one in which no destructive stresses are produced during freezing.

2.2 Aggressive Chemical Exposure

Concrete of good quality will perform satisfactorily when exposed to many chemicals. There are, however, some chemical environments under which the useful life of concrete will be short.

Table 1 lists certain chemicals which attack concrete and recommendations for preventative or remedial protection (Highway Research Board of the National Academy of Sciences, 1966).

Chemical attack on concrete is generally the result of exposure to sulfates or acids, and these are discussed below.

Sulfate attack is a particular problem in arid areas, such as the northern Great Plains area and parts of the western United States. Sulfates such as those found in soils and groundwaters near concrete structures can attack concrete. In the presence of moisture, an expansive reaction takes place between the tricalcium aluminate (C_3A) phase of portland cement and sulfates to produce calcium sulphoaluminate which will cause disruption of concretes. If the C_3A content is lowered during burning of the cement clinker by converting it to tetracalcium alluminoferrite (C_4AF), which is not so suceptible, this produces an effective means of combating sulfate attack.

Type V cement which may not contain more than 5 percent by weight of C_3A, has been found to perform satisfactorily in severe sulfate exposures. Type II cement may not contain more than 8 percent by weight of C_3A and provides moderate sulfate resistance.

In general, portland cement is not acid resistant, but it can withstand weak acids (pH greater than 4.0). Water draining from mines or landfills, some industrial water, and falling rain may contain or form acids which attack concrete. Also, sulfuric acid, carbonic acid, and sulfates are common in ground-water, which could cause corrosion of embedded steel and sulfate attack in concrete.

Acid attack, with the attendent resulting deterioration, is characterized by a chemical reaction between the acid and the calcium hydroxide of the hydrated portland cement. This results in the formation of water-soluble calcium compounds. These in turn are leached away. This total mechanism destroys the binding ability of the cement paste.

Table 1

Certain Chemicals Harmful to Concrete (Effects and Remedies)

Substance	Effect	Remedy
Acetic acid	Causes slow disintegration	Use heavy duty floors with bituminous or polysulfide coatings
Calcium sulfate	Because of limited solubility, attack is less than other sulfates	Use epoxy, rubber, or bituminous coatings: use high quality concrete with high cement factor and air entrainment
Carbon dioxide	No damage to mature concrete, but can dissolve in water to form carbonic acid	Use surface hardeners and coatings: properly vent combustion heaters when placing concrete in heated enclosure
Carbonic acid	Very corrosive to lean mixtures; slowly disintegrates better quality concrete	Use dense, impermeable concrete with high cement factor: use epoxy, neoprene, or vinyl coatings
Fats and oils	Attack varies, depending on concentration of fatty acids and viscosity of oils	Use low water-cement ratio; dense, impermeable concrete; use surface hardeners (Magnesium or zinc flurosilicate), oil-insoluble resin
Hydrobromic acid, hydrochloric acid	Constant contact by strong solution destroys concrete; weak solutions attack slowly	Use protective coatings per ACI 515
Hydrogen sulfide	Sulfuric acid is produced in moist, oxidizing environments, which causes slow disintegration	Use concrete of low permeability; use coatings of polyester, neoprene or epoxy
Iron sulfide	Slow disintegration of low quality concrete if substance contains ferric sulfate	Use good quality concrete; use epoxy, chlorosulfonated polyethylene, or polyester coatings

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Table 1 (Continued)

Substance	Effect	Remedy
Magnesium sulfate	0.5% solution (or more) aggressively attacks concrete with low sulfate resistance, causes disruptive expansion	Use high quality air-entrained concrete with high cement factor; use epoxy, rubber, or bituminous coatings
Nitric acid	Constant contact of strong solution destroys concrete	Use protective coatings per ACI 515
Sodium carbonate in solution	Does not affect mature concrete but causes fresh concrete to deteriorate	Protect fresh concrete from contamination
Sodium chloride	Corrodes reinforcing steel which can damage concrete member	Avoid use or presence of substance
Sodium sulfate	0.5% solutions (and greater) strongly attacks concrete of inadequate sulfate resistance	Use high quality air-entrained concrete with high cement factor; use bituminous, rubber, or epoxy coatings
Sulfur dioxide	Dry gas combined with moisture from acids cause long-term deterioration	Use vinyl, epoxy, or chlorinated rubber coatings
Sulfuric and sulfurous acids	Constant contact with strong solutions destroys concrete	Use protective coatings per ACI 515

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2.3 Abrasion

Abrasion is the wearing away of a concrete surface by rubbing and friction (ACI, 1967). To consider several mechanisms of abrasion, Prior (1966) has recommended four classifications of abrasion:

(1) Wear on concrete floors (foot traffic, light trucking, skidding, scraping, or sliding of objects on the surface).

(2) Wear on concrete roadways (automobiles with studded tires or chains, heavy trucks).

(3) Erosion in hydraulic structures (waterborne abrasive materials).

(4) Wear on water-carrying systems composed of concrete (high velocities and negative pressures).

Abrasion is a physical wearing away or breaking off of material on the surface of the concrete by the abrading agent. The factors, therefore, which affect the abrasion resistance of concrete to a given abrading agent are: compressive strength, aggregate properties, finishing methods, use of toppings or coatings, and curing. Therefore, higher compressive strength results in greater abrasion resistance; harder coarse and fine aggregate results in higher resistance; properly timing the finishing operations and producing a smooth, dense surface gives higher resistance; application of metallic or nonmetallic coatings to toughen the surface gives higher resistance; and, use of proper curing agents for the required time gives a higher resistance.

2.4 Reactive Aggregates

No aggregates should be considered completely chemically inert. Some of the chemical reactions can be beneficial but others can cause disruptive damage such as abnormal expansion, cracking, and loss of strength (Woods, 1968).

The most predominant harmful reaction is "alkali-silica reaction" and is defined as the reaction between hydroxyl ions associated with the dissolution of the cement alkalies (Na_2O and K_2O) and certain siliceous constituents that may be present in aggregates. This disruption is characterized by expansion and severe cracking of the concrete structure.

Another form of reaction is that between the hydroxyl ions associated with dissolution of the cement alkalies and certain carbonate rocks, usually argillaceous dolomitic limestones. The disruptive damage is usually characterized by expansion, cracking, and aggregate degradation.

Other types of chemical reaction include oxidation or hydration of certain unstable mineral oxides, sulfates, or sulfides that occur after the aggregate has been incorporated into the concrete (Highway Research Board of the National Academy of Sciences, 1966).

All of these reactions usually result in such disruptive damage that the deteriorated concrete must be removed and replaced by sound concrete of better quality.

Table 2 is a summary of the deleterious aggregates discussed herein, derived from ASTM (1977).

2.5 Corrosion of Embedded Material

For corrosion of steel embedded in concrete to occur, the following conditions must all be met: (1) the provision of an anode and cathode, (2) the maintenance of an electrical circuit, (3) the presence of moisture, and (4) the presence of oxygen (Mindness and Young, 1981). Under most conditions, good quality concrete provides adequate protection of embedded steel against corrosion. This is due to the high alkalinity of the concrete (pH of about 12 to 12.5) which causes a passive oxide film that prevents corrosion to form on the surface of the steel. The degree to which concrete will provide satisfactory protection is in most instances a function of the quality of the concrete, the depth of concrete cover, and the degree to which good practices are followed throughout the entire construction operation (ACI, 1979).

The quality characteristic of concrete includes low permeability and proper mixture proportions. The permeability of concrete is a major factor affecting the process of corrosion of embedded materials. Low water-cement ratio with well-graded coarse and fine aggregates produce less permeable concrete and thus provide greater assurance against corrosion. Water-cement ratios should not exceed 0.40 for concrete exposed to sea or brackish water, or in contact with more than moderate concentrations of chlorides at the water or ground line. If the water-cement ratio is raised to 0.45, the concrete cover over the steel should be increased 1/2 in. Studies of durability of concrete (seawater exposure) showed that cements containing 5 to 8 percent tricalcium aluminate (C_3A) showed less cracking due to steel corrosion than cements with a C_3A content less than 5 percent (Verbeck, 1968).

Permeability is reduced by increased hydration of the cement. Concrete should be cured properly until at least 90 percent of the design strength has developed.

Table 2

Partial List of Deleterious Aggregates

Andesites and tuffs
Chalcedonic cherts
Dacites and tuffs
Fractured, strained, and
  inclusion-filled quartz
  and quartzites
Opaline cherts
Opaline concretions
Phyllites
Quartzose cherts
Rhyolites and tuffs
Siliceous dolomites
Siliceous limestones
Siliceous shales

Concrete cover over reinforcing steel should be adequate. In a well-cured concrete with low water-cement ratio, the depth of carbonation (calcium hydroxide is converted to calcium carbonate by atmospheric carbonation which destroys protective oxide film on the surface of the steel) is unlikely to exceed 25 mm, and therefore, a concrete cover of 25 to 40 mm over reinforcing bars should be adequate in most instances (Mindness and Young, 1981). Where more severe conditions of exposures are encountered or concrete with fairly high permeability is used, the cover should be increased at least 50 mm (Mindness and Young, 1981). Protection against penetration of salts to reinforcing steel in seawater exposure is 3 in., while the American Association of State Highway and Transportation Officials (AASHTO) recommends 4 in. except for precast piles.

In addition, other practices have to be followed to minimize corrosion. These are good concreting practices (workmanship), good drainage, and good specifications and inspection.

Good workmanship is a most important factor in securing uniform concrete of low permeability. This includes good consolidation and finishing practices, and precaution against segregation.

In areas of severe exposures, particular attention should be given to design details dealing with drainage to insure that the water will drain.

The passive oxide film on steel can be destroyed by chloride ions. Chlorides may enter the concrete from three major sources: (1) admixtures ($CaCl_2$), (2) deicing salts, and (3) seawater. ACI Committee 201 (ACI, 1977) suggests the following limits for chloride ion (Cl-) in concrete prior to service exposure, expressed as a percent by weight of cement.

1.	Prestressed concrete	0.06 percent
2.	Conventionally reinforced concrete in a moist environment and exposed to chloride	0.10 percent
3.	Conventionally reinforced concrete in a moist environment but not exposed to chloride	0.15 percent
4.	Above ground building construction where the concrete will stay dry (does not include locations where the concrete will be occasionally wetted--such as kitchens, parking garages, and waterfront structures)	No limit for corrosion

These limits should be applied with good judgement because other factors such as moisture and oxygen are necessary for electrochemical corrosion.

3. Recommendations for Minimizing Adverse Effects on Long Term Durability of Concrete

The following practices and precautions are recommended to provide durable concrete for aboveground engineered disposal facilities using portland cement concrete as the primary construction material.

3.1 Frost Action

The following items compose the recommendations to overcome frost damage.

3.1.1 Design the structure to minimize exposure to moisture. The building geometry must provide good drainage, with no surface that will provide for potential ponding. Therefore, use a sloped roof rather than a flat roof. Floor slabs must have a vapor barrier between the slabs and grade. Unnecessary joints must be eliminated.

3.1.2 Use low water-cement ratio. For structures of this type the water-cement ratio should not exceed 0.50.

3.1.3 Provide air entrainment in the mixture. It is recommended that air-entrained concrete be used for this construction and Table 3 shows the recommended air contents derived from ASTM (1977).

3.1.4 Use only suitable materials.

3.1.4.1 Cement. The several types of portland and blended cements, in properly proportioned and produced air-entrained concrete, will provide for resistance to cyclic freezing. However, to resist severe sulfate attack, Type V is required. Therefore, for this added protection, Type V conforming to ASTM C 150 is recommended.

3.1.4.2 Aggregate. The aggregates used for this construction should be the very best available, as long as it is cost-effective to obtain them. Careful judgement must be used in deciding the cost-effectiveness factors considering the nature of the material to be disposed. The aggregates should be thoroughly characterized by the physical tests required, i.e., petrographic examination, absorption, specific gravity, soundness tests, and determination of pore structure. These tests are described in the Handbook for Concrete and Cement (US Army Engineer Waterways Experiment Station, 1949).

Table 3

Recommended Air Contents for Freeze-Thaw Resistance

Nominal Maximum Aggregate Size mm	(in.)	Air Content, Percent Moderate Exposure	Severe Exposure
9.5	(3/8)	6	7.5
12.5	(1/2)	5.5	7
19.0	(3/4)	5	6
37.5	(1-1/2)	4.5	5.5
75	(3)	3.5	4.5
150	(6)	3	4

3.1.4.3 Admixtures. Air-entraining admixtures should conform to ASTM C 260.

3.1.5 Use proper curing. Proper curing procedures and materials are required for durable concrete; they should comply with ACI Standard 308-81 (ACI, 1981). Depending on the structural member being cured, the techniques of inundation, water spray, wet burlap, plastic membrane, and sprayed-on membrane are recommended. The curing period should be that established in the laboratory which achieves a specified strength with that particular curing technique.

3.1.6 Use sound construction practices. Good construction practices should be implemented to obtain durable concrete. These include proper mixing, placing, handling, and consolidating of the concrete; protection against extreme temperatures; good forming techniques; use of a form material that will give a smooth dense finished surface; proper curing, especially after form removal; and immediate repair of any surface defects.

3.2 Aggressive Chemical Exposure

Protection against sulfates in the soil or groundwater is achieved by the use of sulfate-resistant cement in dense, high quality concrete with a low water-cement ratio. Table 4 provides certain recommendations for sulfate protection taken from ASTM (1977).

Protection against mild acid attack is achieved by the use of a dense concrete with a low water-cement ratio. However, surface coatings or treatments are required to protect against groundwater, soil, or accidental spills containing high concentrations of acids. ACI Committee 515 (ACI, 1974) has recommended certain barrier coatings for concrete under certain conditions. Table 5 gives recommendations for dampproofing coatings and Table 6 gives recommendations for protective barrier systems. Tables 5 and 6 were taken from ACI (1974).

3.3 Abrasion

Abrasion resistant concrete surfaces will be achieved by implementation of the following measures.

3.3.1 Use low water-cement ratio.

3.3.2 Use well-graded, hard, tough fine and coarse aggregates, with a maximum size of 1 in., meeting the requirements of ASTM C 33 (ASTM, 1981).

3.3.3 Use the lowest slump concrete that is practical for the working conditions (maximum 3 in., 1 in. for toppings).

3.3.4 Air content should be consistent with exposure conditions.

3.3.5 Use a topping layer over the main slab if severe wearing conditions are anticipated.

3.3.6 Finish (float and trowel) the surface only after the surface has lost its sheen.

3.3.7 Vacuum dewatering techniques can be used to remove excess water immediately after placing, resulting in a more dense concrete with increased strength and surface enhancement against wear.

3.3.8 Curing techniques of water spray, damp burlap, or cotton mats are recommended and the curing should be for 7 days.

3.4 Reactive Aggregates

3.4.1 Avoid alkali-reactive aggregates. If possible, reactive aggregates should not be used. However, if their use is unavoidable, they should only be used with low-alkali cement (maximum 0.60 percent equivalent Na_2O).

3.4.2 Determine alkali-carbonate reactivity and use measures to reduce the effects of this reaction.

3.4.2.1 Avoid reactive rocks.

3.4.2.2 Dilute the reactive rocks by the inclusion of nonreactive rocks.

3.4.2.3 Use low alkali cement.

3.5 Corrosion of Embedded Materials

The following measures should be employed to protect embedded items from corrosion:

3.5.1 Use low water-cement ratio.

3.5.2 Avoid honeycombing (provide good consolidation).

3.5.3 Use adequate concrete cover.

3.5.4 Design against structural cracks.

3.5.5 Keep chloride content below permissible values.

3.5.6 Provide protective coating on the concrete.

3.5.7 Provide coating on the steel.

3.5.8 Use good curing techniques.

Table 4

Protection of Concrete Subject to Sulfate Attack

Exposure	Sulfate in Water, ppm	Type Cement Required	Recommended Water-Cement Ratio, max.
Severe to very severe	1,500 to 10,000 and greater	Type V	0.45
Mild to moderate	150 to 1,500 IP(MS) IS(MS)	Type II	0.50

Table 5

Recommended Dampproofing Materials and Techniques

Recommended Material or Technique	Siting Condition: Above Grade Ext. Face	Above Grade Int. Face	Covered or Buried Ext. Face	Covered or Buried Int. Face
Portland cement Paint (water based)	X	X	/	X
Asphalt (cold applied)	X	X	X	//
Latex Paint (PVC)	X	X	/	X
Epoxy Paint (two-component)	X	X	/	X
Chlorinated Rubber Paint(solvent based)	X	X	/	X
Polyurethane Paint (moisture-cured or two-component)	X	X	/	X

/Exterior coating also required (see list in this table for other recommended materials).

//Interior coating also recommended (see list in this table for other recommended materials).

Table 6

Protective Barrier Systems in Chemical Environment

		Protection Against
Exposure	Barrier System	Expected Attack
Severe	Composite system of: (1) Asphalt membrane covered with acid-proof brick and chemical-resistant mortar (greater than 6 mm thick)	Concentrated acid or acid/solvent material
	(2) Epoxy system (sand filled) topped with unfilled pigmented epoxy (0.5 mm to 6.75 mm thick)	Water, dilute acids, strong alkalies, and salt solutions
Severe	Neoprene sheet (precured, PVC sheet (plasticized), glass-reinforced (GR) epoxy, GR polyester (0.5 mm to 6 mm thick)	Organic acids (ph$<$3), salt solutions, strong alkalies
Moderate	Bituminous materials, sand-filled systems of epoxy, polyester or polyurethane (3 mm to 9 mm thick)	Abrasion and dilute acids (intermittent exposure)
Mild	Asphalt, chlorinated rubber, epoxy, vinyl, polyurethane, neoprene, coal tar, coal tar epoxy, coal tar urethane, styrene-acrylic copolymer, acrylic, polyvinyl butyral	Salts (such as deicing), frost damage, solutions with ph$>$4

3.6 Covered Versus Aboveground Structure

The recommendations presented so far have been applicable to aboveground structures. However, if a structure is covered, the information in Tables 5 and 6 must be put to use. The details of the materials and practices will be dictated by the characterization of the cover material. All other recommendations, as shown for the aboveground case, are applicable for underground structures.

3.7 Testing of Component Materials and Final Mixture

Once a decision has been made to construct an engineered disposal facility at a particular location, a test program should be designed and specified that will result in the use of the very best materials to produce the most durable concrete possible. The program should be designed so that the carefully selected components are fully characterized after having been thoroughly tested. The concrete composed of these components should also be fully characterized as to its response to the particular environment.

This program should be followed, once construction begins, with a carefully planned program of quality control and quality assurance. This will insure that the proper components will be used to produce a quality product capable of the high level of durability required.

4. Summary and Conclusions

Adherence to the guidelines and recommendations contained and referenced herein, along with good practices of production and construction, will produce a durable concrete capable of long life. The service life will be further enhanced if proper and timely repair and maintenance procedures are employed, should their need arise. There is no mathematical model that can predict service life of a structure, but by producing the best concrete possible and employing the best construction practices, the implication is that the material and structure will function for many years.

References

1. American Concrete Institute Committee 116, Cement and Concrete Terminology, SP-19, American Concrete Institute, Detroit, 1967, 144 pp.

2. American Concrete Institute Committee 201, 1977, "Guide to Durable Concrete," ACI 201.2R, "American Concrete Institute, Manual of Concrete Practice, Vol. 1.

3. American Concrete Institute Committee 308, 1981, "Recommended Practice for Curing Concrete,"American Concrete Institute Manual of Concrete Practice, Vol 2.

4. American Concrete Institute Committee 515, 1979, "A Guide to the Use of Waterproofing, Dampproofing, Protective and Decorative Barrier Systems for Concrete," No. ACI 515.IR-79, Committee 515, American Concrete Institute, Detroit, Michigan.

5. American Society for Testing and Materials Committee C-9, 1981, "Standard Specifications for Concrete Aggregates (C 33-81)," ASTM Book of Standards, Part 14.

6. American Society for Testing and Materials Committee E-6, 1977, "Recommended Practice for Increasing Durability of Building Construction Against Water-Induced Damage (E 241-77)," ASTM Book of Standards, Vol 04.07.

7. A. R. Collins, "The Destruction of Concrete by Frost," Journal, Institution of Civil Engineers (London), 1944, Paper No. 5412, pp 29-41.

8. R. A. Helmuth, Discussion of "Frost Action in Concrete" by Paul Nerenst, Proceedings, Fourth International Symposium on the Chemistry of Cement (Washington, D. C., 1960), Monograph No. 43, National Bureau of Standards, Washington, D. C., 1962, Vol 2, pp 829-833.

9. Highway Research Board of the National Academy of Sciences - National Research Council, "Symposium on Effects of Aggressive Fluids on Concrete," (6 Reports), Highway Research Record, No. 113, 1966, Washington, D. C.

10. G. G. Litvan, "Phase Transitions of Absorbates: IV, Mechanism of Frost Action in Hardened Cement Paste," Journal, American Ceramic Society, Vol 55, No. 1, Jan 1974, pp 38-42.

11. R. Malinowski, "Concrete and Mortars in Ancient Aqueducts," Concrete International, Jan 1979.

12. S. Mindness and J. F. Young, *Concrete*, Prentice Hall, 1981.

13. T. C. Powers, "A Working Hypothesis for Further Studies of Frost Resistance of Concrete," ACI Journal, Proceedings, Vol 41, No. 4, Feb 1945.

14. T. C. Powers, "Void Spacing as a Basis for Producing Air-Entrained Concrete," ACI Journal, Proceedings, Vol 50, No. 9, May 1954, pp 741-760.

15. T. C. Powers, "Basic Considerations Pertaining to Freezing-and-Thawing Tests," Proceedings, ASTM, Vol 55, 1955, pp 1132-1155.

16. T. C. Powers, "The Mechanism of Frost Action in Concrete," Stanton Walker Lecture No. 3, National Sand and Gravel Association/National Ready Mixed Concrete Association, Silver Spring, Maryland, 1965, 35 pp.

17. M. E. Prior, "Abrasion Resistance--Hardened Concrete," *Significance of Tests and Properties of Concrete and Concrete-Making Materials*, STP 169A American Society for Testing and Materials, Philadelphia, 1966, pp 246-260.

18. D. M. Roy, and C. A. Langton, 1983, "Characterization of Cement-Based Ancient Building Materials in Support of Repository Seal Materials Studies," Report No. ONWI-523, The Materials Research Laboratory, Pennsylvania State University, University Park, Pennsylvania, 31 Dec.

19. U. S. Army Engineer Waterways Experiment Station, CE, *Handbook for Concrete and Cement*, Aug 1949 (with quarterly supplements), Vicksburg, MS.

20. G. J. Verbeck, "Field and Laboratory Studies of the Sulphate Resistance of Concrete," *Performance of Concrete--Resistance of Concrete to Sulphate and Other Environmental Conditions*, Thorvaldson Symposium, University of Toronto Press, Toronto, 1968, pp 113-124.

21. George Verbeck, and Robert Landgren, "Influence of Physical Characteristics of Aggregate on the Frost Resistance of Concrete," Proceedings, ASTM, Vol 60, 1960, pp 1063-1079.

22. Hubert Woods, *Durability of Concrete Construction*, Monograph No. 4, American Concrete Institute/Iowa State University Press, Detroit, 1968, pp 57-68.

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13. ABSTRACT (200 words or less)

The study reported herein contains the results of Task 2e (Technical Requirements for Shaft Disposal of Low-Level Radioactive Waste) of a four-task study entitled "Criteria for Evaluating Engineered Facilities." The overall objective of this study is to ensure that the criteria needed to evaluate five alternative low-level radioactive waste (LLW) disposal methods are available potential license applicants. The shaft disposal alternative is one of several methods that may be proposed for disposal of low-level radioactive waste. In this report, the term shaft disposal refers to a near-surface disposal alternative in which the wastes would be disposed of in shafts or boreholes augered, bored, or sunk by any other conventional method. The experience and knowledge gained with this method are described and updated in this report. This includes experience in the use of shafts for storage in the U.S. and Canada and research with the method both here and abroad. A generic description of the features and components and operation of a shaft disposal facility is provided. Features and components that could enhance the long-term performance are described, including site conditions for which they would be applicable. The applicability of existing criteria developed for near-surface disposal (10 CFR Part 61 Subpart D) to the shaft disposal method, as assessed in Task 1, are reassessed herein. Without exception, these criteria were found to be applicable in the reassessment. These conclusions differ slightly from the Task 1 findings.

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